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Special Issue Reprint

Design and Sustainability

Edited by
Santosh Jagtap and Lucia Corsini

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Design and Sustainability

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About the Editors

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Preface to "Design and Sustainability"

Design plays an important role in addressing the social, economic and environmental challenges faced by societies around the world. Appropriately designed solutions contribute towards health, well-being, inclusivity and the sustainable development of life for people living in rural, urban and remote areas. Designing sustainable solutions is thus necessary to support the social and human development of individuals and societies around the world, and to contribute towards achievement of the UN Sustainable Development Goals (SDGs). These solutions can manifest in many different forms, including as products, services and product service systems (PSSs). The process of designing these solutions profoundly affects their technological, functional, aesthetic, ergonomic and many other attributes, having a significant impact on their environmental, social and economic qualities.

This Special Issue, entitled "Design and Sustainability", aims to foster discussion on the design and development of products, services and PSSs that are socially, economically and environmentally sustainable. It is crucial to consider various facets of design and sustainability in a broad range of sectors and countries, while also paying attention to the often overlooked 'softer' dimension of social sustainability.

The Special Issue comprises 14 articles and covers a broad range of topics in the field of design and sustainability. The studies focus on various sectors and countries. The articles report studies on sustainability considerations in teaware design, social innovation and sustainability in the case of bamboo craft, design methods to deal with sustainability issues in poultry sector, and affective interaction in the case of public transport systems. In addition to these articles, the Special Issue includes studies that investigate the role of codesign in developing sustainable products, services, and systems. These studies examine the development and evaluation of codesign toolkits to support the design of energy innovations, explore the ways in which service design and collaborative processes can promote sustainable services in cities, and determine how participatory storytelling can invoke empathy for nonhuman stakeholders. A further group of articles examines design activities in informal metalworking microenterprises and sustainability issues in SMEs involved in the design and manufacturing of furniture. The collection also includes studies on strategies for visual communication design in order to support and maintain connections between products and consumers, cradle-to-cradle principles in the conceptual design phase, design of tasks to facilitate distance learning in emergency situations such as pandemics, and impact of local context on community-based design projects.

In conclusion, the Special Issue is as a call for action for all relevant stakeholders involved in designing sustainable products, services and systems in a variety of sectors and countries. It is hoped that it will inspire companies, NGOs, governments, and any other stakeholders to embrace sustainable design practices. We expect that this Special Issue will serve as an important resource for all stakeholders interested in improving design practices for the creation of sustainable solutions.

Santosh Jagtap and Lucia Corsini

Editors

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Article

Towards Systemic Innovation Programmes for Sustainability Transitions: A Comparative Study of Two Design-Led Cases

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Abstract: Sustainability Transitions challenge current practices deeply entrenched through vested interests in dominant regimes. In this sense, actors are locked into paradigms that are systemic and resilient to change. In response, opportunities within designerly approaches encompassing systemic innovation's dynamic, multi-stakeholder and interconnected nature are investigated. The adoption of such approaches is evident among progressive actors facilitating systemic collaborations. Consequently, this paper proposes Systemic Innovation Programmes as a concept to define such initiatives, particularly for addressing sustainability transitions. Two contemporary programmes in Norway are presented, and a comparative analysis is made by linking key frameworks from the systemic design and transition to the management literature to clarify their tangency to intentional, sustainable systems change. The study identifies a spectrum of programmatic and faciliatory considerations in practice that broadly aligns with important frameworks from the systems research; however, they are rarely formalised in the programmes' methodology or framing conditions. Thus, the theoretical contribution aims to inform systemic practitioners and policymakers in further integrating sustainable transition perspectives into future systemic change initiatives.

Keywords: systemic design; systems change; sustainability transitions; transition management; sustainability-oriented innovation

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1. Introduction

Grand challenges, such as climate change [1] and environmental degradation [2], are critical, urgent, and systemic in nature. Commonly, it entails that they are complex, interconnected across sectors and actors, and resilient to change [3]. Furthermore, efforts to intervene and direct systems-wide changes are associated with high levels of uncertainty given their long timeframes and inherent complexity and, thus, at risk of unintended and unwanted effects [4]. A growing community of researchers are investigating how such transitional journeys can come about in a just manner that acknowledges planetary and social boundaries [5], defined as sustainability transitions [6–8].

The current research agenda of the STRN [9] affirms an understanding of sustainability transitions as an interconnected, highly collaborative and interdisciplinary endeavour. New technologies and infrastructures are needed, but increasing attention must also be given to the social dynamics, practices, and mental models that constitute the human element of our socio-technical systems [10]. Thus, we must also investigate the organising and facilitation of the processes that influence and create interventions intended for systems change. In response, we observe an interplay between two bodies of research: transition management [11] and systemic design [12]. Several characteristics of systemic processes lend themselves naturally to a designerly approach. The participatory-, interdisciplinary-, and multi-stakeholder aspects of transitioning argue for reflexive facilitation and knowledge brokering that have a long tradition in designerly practices [13–15]. The contribution of design as a catalyst for (business) innovation is also extensively described [16–18], and lastly, studies into the applicability of design in sustainability-oriented, complex contexts are developing [19–21].

This paper explores these links further by studying systemic initiatives defined as Systemic Innovation Programmes (SIP). Such emergence of novel, multi-actor initiatives [22] is essential for systems-level change, as they enable new ways of establishing mandate, legitimacy, dialogic learning, and creating innovations [23]. However, multi-actor collaboration is fraught with issues, such as conflicting agendas and interests, the strategic positionality of business, intellectual property, and similar central factors of current business logic and economic paradigms [24]. Moreover, the longer timelines of systemic innovations frequently conflict with the demand for short-term gains, impacting the fostering of substantial, lasting change. Ultimately, such collaborative efforts in sustainability transitions are experimental with an inherent uncertainty of outcomes, making scoping and agenda-setting challenging [25].

Knowledge still needs to be improved, particularly regarding structural elements that frame the scope and latitude of systemic initiatives. To address this research need, a review of key literature is presented, followed by a case study of two SIP. Thus, this paper aims to inform practitioners and policymakers in the future development of systemic change initiatives in terms of processes-design and framing conditions.

2. Theoretical Background

To present the most relevant literature that this study draws from, we organise this section into Systems theory; Sustainability transitions and transitions management; Systemic design and -innovation; and emergent role of design in sustainability transitions (Figure 1). Lastly, an alignment of frameworks is identified to support the case study.

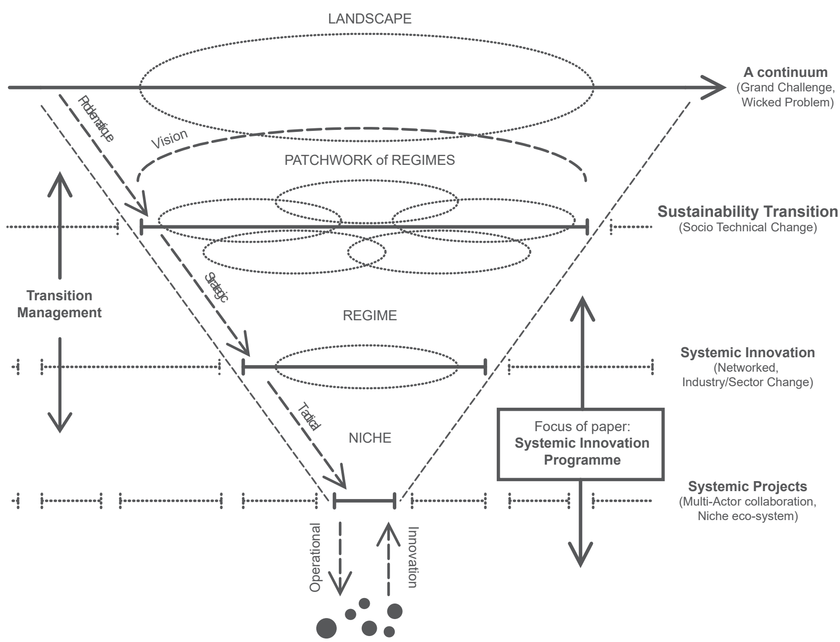

Figure 1. Schematic overview of key concepts and orientation of the study. Based on [11,26,27].

2.1. Systems Theory

The characteristics of contemporary societal issues suggest that sustainability is a systemic endeavour and must be addressed as such [28]. The complexity that arises from the interconnected, multi-level, multi-stakeholder contexts call for perspectives that can engage with macro, meso and micro perspectives as a dynamic whole. Systems theory and systems thinking [29–31] offer a holistic approach, focusing on synthesis and encouraging exploration of inter-relationships (i.e., context and connections), boundaries (i.e., scope, scale), and engagement with actors and stakeholders. Such perspectives have increasingly influenced research and practice that engage with systemic issues beyond diagnostics towards systems interventions for sustainability transitions.

The transitioning of societal-scale systems through historical perspectives is thoroughly examined. Notable contributions include the theories of multi-level perspective [32] and socio-technical transitions [26]. The multi-level perspective provides a heuristic that transitions in our built systems are made up of interacting analytical levels—landscape, regime, and niche in which embedded phenomena, including technologies, processes, regulation, knowledge and culture–influence actors' behaviour. Over time, the practices, or "way of doing", of the system will become path dependent through the vested interests of the actors [26] forming a regime. Still, changes to socio-technical systems happen; Their inherent resistance to change is challenged by powerful events (globalisation, digitalisation, climate change) at the landscape level, understood as the larger encompassing context of the regime. Such events can exert enough force on the dominant operational logic of the incumbent regime, presenting "windows of opportunity" to allow the introduction of novel innovations and practices from the niche level to infiltrate the regime, ultimately reconfiguring it by fitness analogous to an evolutionary perspective [33] (p. 4). However, the acute sense of urgency and criticality to current grand challenges has given increased attention to possible ways of accelerating regime shifts through systemic interventions and the intentional governing of such transitions.

2.2. Sustainability Transitions and Transition Management

Sustainability transitions [6,34] add a normative, interventionist imperative to systemic change. A notable definition describes it as *"long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption"* [8] (p. 956). Transitioning of socio-technical systems comes with several challenging issues involving rippling effects and change along different dimensions and actors over considerable spans of time [8]. Furthermore, they include changes in social behaviour, practices, and institutional structures. Business models, services, and products are substituted throughout such transitional processes, partly driven by innovations or reconfiguration and complementation of incumbent solutions. The consequent disruption of markets, organisations, technologies, practices, and socio-cultural dynamics can cause considerable harm through unwanted effects and unintended consequences. An obvious tension is thus present as the types of transitions in question are deliberate, purposeful, and normative. To this effect, sustainability transitions incorporate guidance and governance as crucial aspects of the transformation process [34].

The intentional establishing of visionary futures, mass coordination of actors, and strategic orchestration of long-term systemic change strategies have found emergence in the transition management research. Its theoretical roots can be traced from system theories, governance, and strategic (niche) management. An instrumentalist and interventionist approach, it proposes strategic, governing influence on transitions towards more sustainable futures: *The hypothesis underlying transition management is that (collective) understandings of the origin, nature and dynamics of transitions in particular domains will enable actors to better anticipate and adapt to these dynamics so as to influence their speed and direction.* [35] (p. 49). Moreover, it fundamentally acknowledges the need to engage with the networked interdependencies between actors across sectors following the recognition that grand societal challenges are too complex to be solved by any sole actor [36]. Rather than being concerned with policy alone, transition management includes the vantage point of emerging innovations (in technology, business models and practices) at the mesoscale. Leveraging these elements contribute to solutions at the macro-scale, ultimately increasing the potential for course change of current, unsustainable regimes.

2.3. Systemic Design and Innovation

The systems and transition theories are increasingly influencing design research, informing new ways to bridge the theory and practice of systemic innovation projects approached by designers. The evolving field of complexity-oriented research, such as systemic- and systems-oriented design, is arguably a response to meet the contemporary challenges presented by clients and society: *"Systemic design can be conceived as optimising processes for group design and decision making under conditions of overwhelming conceptual complexity."* [37] (p. 16).

Designerly approaches have evolved a distinct propensity towards human-centred and constructivist approaches [38]. Thus, they exhibited their efficacy for complex problem-solving [39,40] through their capacity to engage with the dynamics of humans and objects in context. This is evident with deep insight processes latent in design practices that observe systemic behaviours, are deemed critical to identify, and manifest leverage onto systems for lasting change [41]. Thus, design is approached with interest from a systemic innovation perspective, as seen in recent literature [42–44]. More explicitly, Ceschin explored the coupling of design and strategic niche management as intentional reconfiguring towards sustainable product-service systems, emphasising the importance of designers operating strategically to develop effective system innovations [45]. Joore and Brezet identify multiple levels of engagement in the design of products, product-service solutions and, ultimately, systems in a process framework to orientate and coordinate any designed intervention in a multi-level perspective [46]. A common thread in this nascent body of literature is the expansion of design practitioners' role in systems innovation, from a product and service solutions (artefact making) orientation towards facilitation and design of strategy, organisations, and system-change processes. Thus, systemic design is approached with interest from the sustainability perspective, as identified by a recent literature review [21].

2.4. The Emergent Role of Design in Sustainability Transitions

Consequently, the emergence of a new role for design becomes evident, which includes the planning and facilitation of systemic innovation in sustainability transitions, even suggested to take the form of human agents mediating transition efforts explicitly [47] (p. 4). A further linking of design and transitioning is explored with socio-technical skills [48], design for sustainability transitions [49], and transition design [50]. With this new role, it becomes imperative that designers gain new operational insight by interfacing with the strategic, governing influence of transition management. However, this would, in turn, require new design processes and skills to be integrated into design-led systemic innovation projects. *"If designers want to play a more effective role in the transition towards sustainability they should be aware of the mechanisms and dynamics that regulate the implementation and diffusion of sustainable radical innovations—and how it is possible to guide and orient them."* [43] (p. 18).

Thus, transition management and systems-related design frameworks, namely *Transition Management Cycle* [11]; *Transition Activities* [51]; *Strategies for Systemic Innovation* [52] and *Systemic Design for Socio-Technical System Innovation* [53], are identified towards a combined framework for evaluating SIP. The author argues that these frameworks are of particular interest for this investigation as they are: (i) rooted in prominent work on socio-technical systems and transition management, (ii) directly integrated into designerly approaches by design scholars, and finally, (iii) all declare a need for further studies into "real-world application". Consequently, their theoretical relations and the resulting combined framework used for evaluating the cases are described in Section 4.2 and the discussion of this paper.

2.5. Synthesising the Key Framework for Evaluating SIPs

The following graphical representation in Figure 2 argues for several interconnecting and correlating elements of four key frameworks deemed relevant for studying SIP.

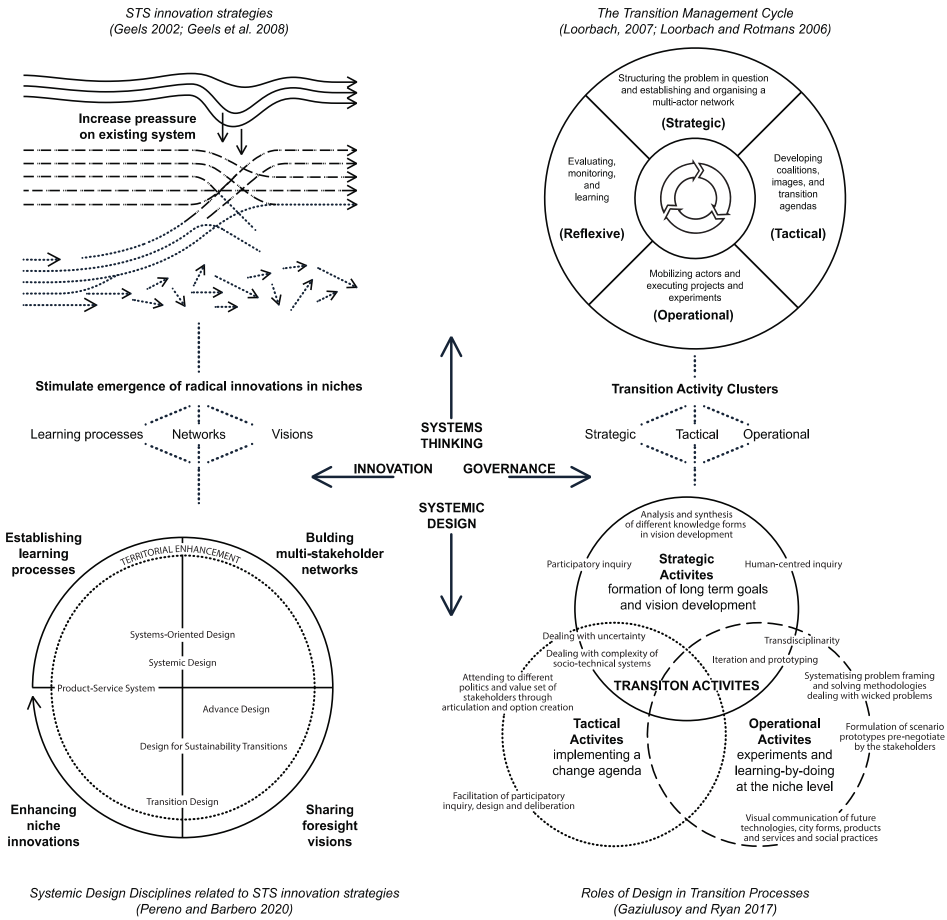

Figure 2. Relational overview of key frameworks from socio-technical studies, transition management and correlating frameworks from systems-related design. Based on [11,26,51–54].

The resulting new, combined framework presented in Section 4 aids in structuring the following discussion, functioning as an analytical lens to evaluate the two case studies of this paper. The four key frameworks can further be organised into two complementary sets to clarify their alignment and distinctions:

- Relating to *Transition Management:* Transition Management Cycle [11] and Transition Activities [51].
- Relating to *Systemic Innovation:* Strategies for Systemic Innovation [52] and Systemic Design Tools for Socio-Technical System Innovation [53].

2.6. Relating to Transition Management

The *transition management cycle* is a way to organise the so-called systemic instruments [11] (p. 114) in a process with four key phases: (i) Structure the problem in question, develop a long-term sustainability vision and establish and organise the transition arena; (ii) Develop future images, a transition agenda, and derive the necessary transition paths; (iii) Establish and carry out transition experiments and mobilise the resulting transition networks; and (iv) Monitor, evaluate, and learn lessons from the transition experiments and, based on these, make adjustments in the vision, agenda, and coalitions.

The cyclical phases do not represent a strictly sequential process but a need for related activities and outcomes. Furthermore, the transition management research identifies three accompanying activity clusters: *Strategic activities* that involve forming long-term goals and visions. Second, *Tactical activities* are concerned with implementing a transition agenda and connecting actors and activities towards the goal. Finally, *Operational activities* related to learning by doing at the niche level, often through experimentation and disruptive innovations [11] (p. 125). These clusters formed the basis upon which the 12 roles of design, as identified by Gaziuluzoy and Ryan, have been mapped and organised into three categories *in inquiry*, *in process*, and *in outputs*—corresponding to the three activity clusters in transition management. These design roles resulted from observing a 4-year transition project (VP2040), in which only a few were explicit. At the same time, the majority was related to inquiry and process, in alignment with the emerging role of design practitioners as facilitators in complex projects.

2.7. Relating to Systemic Innovation

The "*Systemic Design Disciplines for Socio-Technical System innovation strategies*" framework suggests that six systems-related design disciplines can be mapped onto four strategic transition approaches [53]. The Four strategic approaches (or niche-oriented innovation instruments) include (i) Stimulating the emergence and development of radical innovations in niches; (ii) Learning processes: R&D subsidies, subsidies for programmes of experimentation and pilot projects, codification and exchange of experiences, training and competence building, and procurement; (iii) Networks: network management methods, participatory methods to facilitate multi-stakeholder interactions, new platforms, or meeting places, debates, and negotiations, including outsiders or frontrunners; and (iv) Visions: foresight exercises, scenario workshops, and ways of translating long-term visions to short-term actions [52]. Pereno and Barbero continue expanding on the disciplines by identifying 16 related designerly tools deemed applicable in activating the four strategies above:

First, *establishing learning processes* suggests using Holistic Diagnosis and Gigamapping to provide an overview of the complexity involved in systemic innovation. The second strategy, *building multi-stakeholder networks*, focuses on co-creation and stakeholder inclusion through tools like Structured Dialogic Design and Stakeholder Configuration Design. The third strategy, *sharing foresight visions*, seeks to establish collective understanding and strategic vision through the Double-flow scenario method and Multi-level Design Model, among others. Lastly, the fourth strategy of *enhancing green niche innovations* is directed towards the importance of protected spaces for innovations and solutions outside the established regime. As such, the tools address the experimentation, scaling-up and policy aspect of niche innovations.

3. Method and Cases

This study investigates the structural organisation and theoretical lineage of two SIP through the perspective of systemic design and transition management. A multi-stage qualitative approach was chosen, including a literature review, framework development, and a comparative case study, as "*qualitative research methods are designed to help researchers understand people and the social and cultural contexts within which they live.*" [55].

The overall process was structured as depicted in Figure 3.

First, the key literature related to (socio-technical) systems theory, sustainability transitions, transition management, and systemic design was identified and reviewed to clarify the notion of SIP. Second, select frameworks from the abovementioned literature were studied and synthesised into a combined framework according to their interrelatedness and complementary aspects for analysing SIP. Subsequently, the two cases of the study were presented, and central aspects of their structure were identified and compared to interpret their academic lineage, methods, practices they infer and outcomes that might be achieved. The main data source was primary documents [56]; That is, content created and made available by the programme owners or partners of the cases and has not been manipulated by the researcher. This includes publications, websites and media content intended for broad, unfacilitated dissemination. Therefore, it could be argued that the documents can be evaluated as contained, stand-alone 'social facts', which are produced, shared, and used in socially organised ways" [57] (p. 47). A complete list of the documents used for this study can be found in Appendix A. Lastly, a discussion of the two programmes' alignment with the combined framework was conducted to reflect on their efficacy for sustainable transitioning.

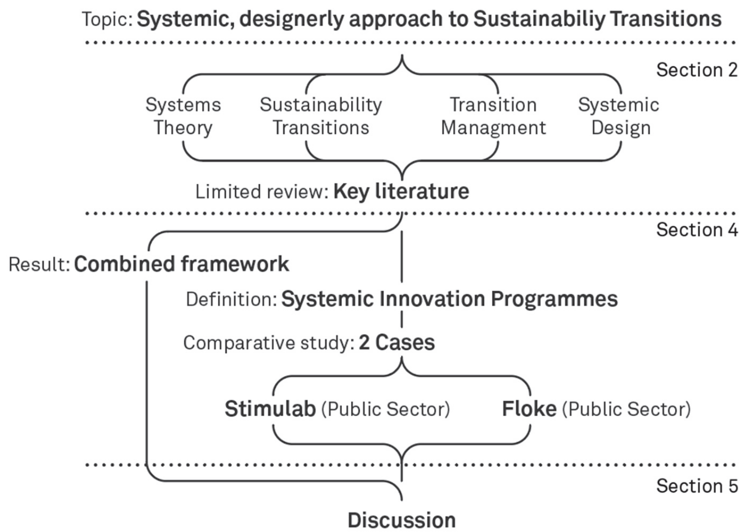

Figure 3. Research methods and processes adopted by this study.

It should be noted that the study is part of a broader investigation, beyond this paper, into the emerging role of designers as facilitators of systemic change. That is systemic practices that are situated, social, and relational. The research draws a clear lineage to design practice from the ideas of pragmatism. Dalsgaard has made this link explicit when drawing on pragmatism to prompt a proper understanding of a systemic design situation [58]. This perspective is reflected in the recent development of systemic design, which gravitates toward pragmatism and pluralism [59]. Sevaldson suggests the field itself observes an emergence of generative, adaptive and dynamic design- one in which the so-called real-life context of the challenges drives a primacy of practice; " ... *if the models do not fit, or they are too cumbersome to operate, they need to be changed.*" [59] (p. 1).

Two Cases of Systemic Innovation, Stimulab, and Floke

Due to their specific characteristics, two systemic initiatives in Norway were deemed particularly interesting for investigating the notion of SIP in this study. They are distinctively multi-stakeholder and inclusive processes with ambitions of systems change. Furthermore, they are explicitly design-led, adopting designerly approaches to facilitation.

The StimuLab (Official StimuLab webpages) programme was initiated in 2016 by Design and Architecture Norway (DOGA) and the Norwegian Directorate of Digitalisation (DigDir) on assignment by the Norwegian Ministry of Local Government and Modernisation. It was developed to increase the understanding and utility of human-centred approaches to public sector innovation and has funded 42 projects by 2023. It has identified three key contributions: (i) Facilitate and initiate innovative approaches to public service development, (ii) Connect and utilise existing design-competency in the supplier market, and (iii) Offer a methodology to approach complexity in challenges [60]. The rationale is that the quality of public service offerings will increasingly depend on the ability to include designerly approaches to innovation that integrate better identification of needs, challenges, and seamless user experiences across channels and touchpoints. It is to be noted that Stimulab is publicly funded through a governmental policy initiative and thus expected to acknowledge ambitions set by principal governmental reports and guiding documents, such as *Digitaliseringsstrategien* and *Innovasjonsmeldingen.* Funnelled through the *Innovative Procurement* format, suppliers are invited to bid on individual projects that DOGA and DigDir manage on behalf of project owners in the public sector. DOGA guides the process, identifying competence and experience as needed, tailored to each project. An interdisciplinary approach is expected, resulting in frequent consortiums of suppliers answering the project calls. This development also reflects the increasing systemic nature of the projects funded in recent years.

The privately held Floke (Website of Floke programme) initiative was coined as a societal innovation programme by its founding organisation, Æra Strategic Innovation, and developed with the conviction that the private sector must take an integral role in addressing the grand challenges of our time. Floke is structured around three distinct core elements: (i) Quadruple Helix collaboration, reflecting that no sustainability challenge can be solved by single actors alone and that collaboration must cross traditional boundaries made by sector and industries; (ii) Open innovation approach that argues for learning and creative processes outside the organisation's internal structures to accelerate radical innovations; and (iii) A designerly approach to strategic business innovation to leverage the participating actors' resources and competencies for engaging with grand challenges by developing an innovative portfolio of synergetic solutions. The programme has initiated 11 projects in several industries and thematic areas, with challenges ranging from sustainable food consumption to circularity in the construction industry. The programme owner and independent domain experts initiate the projects, identifying and investigating grand challenges receiving increased momentum, forming a so-called innovation brief based on insight and knowledge that becomes the call to action. Consequently, relevant actors and key stakeholders are invited as co-funding participants in the main innovation projects, and solutions concepts developed in the project are owned collectively by the participating actors. As a result, numerous ventures have spun out from the programme in the form of new collaborative business ventures, novel product-service solutions, and collaborative strategies.

Both cases presented are total units of analysis with an extensive historical record. However, this study mainly concerns their most current iteration and practices. Thus, the programmatic perspective is supplemented by investigations into recent projects within the programmes to study real-world effects and implications of praxis. As such, they become proxies for recurring phenomena and issues that can support a holistic perspective of programmes beyond their core narratives.

4. Results

This section presents the main contributions of this study, including the combined evaluative framework, a further extension of the concept of SIP, and a comparative overview of the Stimulab and Floke programmes.

4.1. A Combined Framework for Comparative Analysis

The graphical representation in Figure 4 identifies fundamental relational concepts of the designerly approaches to *transition management* and *strategies for systemic innovation*. A further structuring for this study's investigative purpose is achieved by combining the essential elements into an integrated framework. The framework maps designerly contributions related to levels of engagement and links them to the overarching strategies identified by the multi-level perspective and transition management. This is subsequently used in the discussion section as an analytical lens to structure the investigation into the structural design of SIP and their applicability to sustainability transitions.

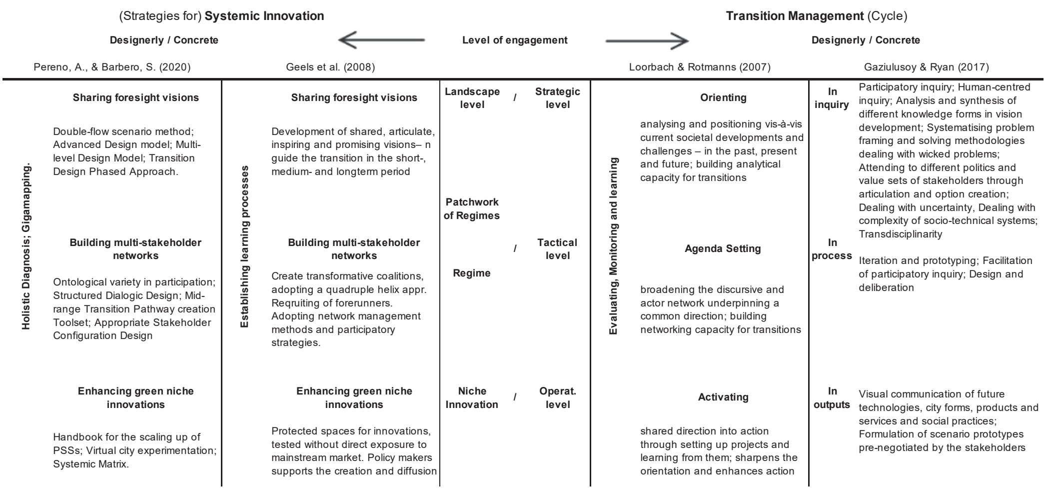

Figure 4. A structured overview of the four frameworks shows their interrelated key concepts along a systemic innovation and transition management continuum.

4.2. Expanding the Concept of Systemic Innovation Programmes

This study is concerned with the nature of *programmes*. While the term is used interrelatedly with *projects*, several important distinctions of the former's specific structural and managerial characteristics are argued in the literature [61,62]. In management theories, the programme has evolved to encompass and grow beyond wholistic project concepts as a means to engage with challenges that argue for flexibility and benefit realisation beyond the means of the traditional project scope: "*In particular, they suggest that programmes are better at addressing contents and contexts of change characterised by environmental uncertainty and/or ambiguity, complexity, embeddedness and sheer scale*" [60] (p. 235).

A SIP has the ambition of challenging the conditions holding systemic issues in place while acknowledging that such shifts are complex, to the extent that a partitioning into multiple initiatives might be preferable. That is, in managing and coordinating synergistic effect, breaking a grand challenge into sub-projects, addressing different aspects of a composite problem. Furthermore, SIP seeks to frame the initiative in an explicitly experimental narrative, acknowledging the open-aperture approach deemed fundamental for systemic innovation [63]. A further distinction is that SIP focuses on innovation as an interventionist approach, whereas transition management commonly directs attention towards governing influence and policy processes. The SIP cases investigated are also shorter in timespan than suggested in transition management initiatives that could span decades [11] (p. 197). However, definitions are naturally overlapping, as can be seen in an example, which states: "*We, thus, understand systemic innovation and transition programmes as integrated strategies that aim—through coordination structures and activities—to achieve alignment between a set of policy instruments that target different parts of the system.*" [64] (p. 1).

Similar nomenclatures describe novel collaborative endeavours, such as *innovative multi-actor collaborations* [65] or *systems-oriented innovation* [23]. However, SIP is proposed to precisely orientate the study towards the programme as a structural unit of analysis. For the intent of this study, we define SIPs as:

- An open innovation, a responsible initiative [66] that seeks to:
- Organise actors and stakeholders around grand challenges [67].
- Predominantly a multi-actor, cross-sectoral collaboration [68].
- Anticipatory, collective agenda-building for future visions [11] (p. 90).
- A lasting initiative seeking long-term benefit, i.e., learning and evolving capabilities [69], while exploring short-term actions.

- A set of repeatable structural elements (to predict outcomes and minimise risks), such as projects with prescribed forms, boundaries, and tangible deliverables:
- That works synergistically to effect systemic change [62].

4.3. Comparative Analysis of Stimulab and Floke

The two cases of this study not only conform with the 7-point definition as described in the previous section but, more importantly, they integrate two additional key elements that are central to the author's ongoing research: (i) They are explicitly design-led in both the facilitatory approach and the promotion of designerly methods and tools. (ii) They have an extensive track record of projects executed in respective programmes, thus amassing significant learnings that have evolved their approaches.

The following structured table (Table 1) identifies and compares their key characteristics relating to designerly approaches to systemic innovation:

Table 1. Case overview, including key aspects of the two SIP in question (and theoretical references).

Programme Aspects	**Stimulab**	**Floke**
Rationale	Stimulating experimental approaches to grow innovation capacities in the public sector and strengthening collaboration with private-sector suppliers.	Sustainability Oriented Innovation through multi-actor cooperation for addressing societal-scale challenges by activating resources and competencies in the private sector.
Programme Ownership	Governmental; Norwegian Architecture and Design (DOGA), Directorate for digitalisation (DigDir).	Privately held; Æra Strategic Innovation (Business consultancy company).
Beneficiaries	Public sector actors and organisations, general public.	Companies, NGOs, and public sector actors that are affected by the challenge.
Key Actors	Multi-stakeholder; Programme owner, project beneficiary, supplier (consultant).	Multi-actor, cross-sectoral Quadruple helix approach.
Stakeholder inclusion	Consulted, Co-Design, Ladder of Citizen Participation [70].	Project owners: Co-design, co-production Eight strategies for co-creation [71].
High level concepts	Mission orientation [72] for creating long-term sustainable, efficient, and quality public services.	Transitioning of industries and sectors towards more sustainable value creation [73].
Systemic perspectives	Wicked Problems [74].	Wicked Problems [75], Persistent critical challenges [76].
Transition/ Change paradigm	Systems change [41], Niche innovation and portfolio strategy.	Socio-technical change theory [27,77], Developing a portfolio of niche innovations.
Sustainability paradigms	Sustainable Development [78].	Sustainable Development [78], Triple Bottom Line [79].

Table 1. *Cont.*

Programme Aspects	Stimulab	Floke
Innovation paradigm	Public sector innovation [80].	Open Innovation [81], Shared Value [82].
Designerly Approaches	Human-Centred Design, Service Design, Design Thinking [83].	Business Design [84], Sensemaking [85,86], Systems Thinking [29].
Designs main role	Designers as creative problem solvers, Design as a cognitive style [87].	Designers as facilitators and knowledge brokers, Design as an organisational resource [87].
Designerly methods/tools	Participatory design, visualisation, and iterative prototyping.	Co-design, visualisation, and prototyping.
Funding	Governmental grant, accessed through procurement processes.	Initial phase is sponsored by programme owner and project partners. Main phases funded by participants (project fee).
Project owners	Consultancy winning tender, Single company or consortiums.	Consortium initiated by 2–3 lead actors, Co-financed by all project participants.
Project participants	1–3 Beneficiary actors, 1–3 suppliers -Studio scale [37],	30–40 participants, 10+ actors, and Arena scale [37].
Project lengths	Annual cycle: 2–5 project started; 5–10 months scoping and onboarding + 6–18 months project run-time.	Annual cycle: 4 projects a year; 5–6 months scoping and onboarding + 6–8 months project run-time.
Challenge scoping (project scope)	The overarching theme is established. Additionally, calls for applications are opened. Evaluation of incoming applications by any public actor. -> Resulting in a public procurement call, open for qualified suppliers.	Identification of persistent, critical challenges with a societal interest and actuality. The topic chosen and researched for background -> Resulting in a call to action, recruiting actors and stakeholders.
Selection criteria	User-focus and identified user-needs, Clear innovation potential, Multi-actor, cross-disciplinary, Generalisable learning and knowledge,	Societal actuality and momentum, Collective agreement on innovation scope, Cross-sectoral interest and participation, Sufficient value chain representation of actors.
Process/ Methodology	Stimulab "Triple Diamond", 3-stage process: Divergent-Convergent thinking/CPS [88], Double Diamond process [89].	"Floke approach", innovation process: Divergent-Convergent thinking [88], Double Diamond process [89], Three-box solution [90].
Process phases	Three cycles (six phases): 0. Understand/Onboarding/Commitment 1. Diagnosis, 2. Explore + Define, 3. Develop + Deliver.	Six phases, two cycles: 0. Pre-project 1. New Insights, 2. New Ideas +3. Concepts, 4. Experiments, 5. Realisation.
Evaluation and Control mechanisms	Dialogue meetings (supplier, beneficiary, program owner), Brief update (problem-/solution scope).	Foundational knowledge report/ Innovation Brief, Core meetings (Facilitator/programme owners + project partners).

4.4. General Consideration of the Cases Relating to Transferability and Applicability

It should be emphasised that the type of ambitious cross-sectoral, multi-actor systemic initiatives represented in this study are currently a rare breed. Furthermore, the two case examples are from Norway and cannot cover a diversity of working-context, such as perspectives from the global south, developing countries, and rural areas. These scope limitations must be considered for further research, such as the possible development of generalisable characteristics towards typology or even theory-building. In this sense, the cases were chosen more in the function as a set of critical issues, constituting a powerful example [91] (p. 20) with the intent to understand "how" and "why" [92].

5. Discussion

The following section discusses central attributes of systemic, multi-actor innovation in systemic programmes. First, select, generalisable aspects are covered before the two cases are addressed in a structured investigation through the application of the combined framework, including (i) *Establishing of learning, monitoring and evaluation perspectives* and the three levels of analysis; (ii) *the Landscape/Strategic level*, (iii) *the Regime/Tactical level*, and (iv) the *Niche/Operational level*.

5.1. Project Initiation and Framing from the Systemic Programmes

The programmatic approach is beneficial in engaging with systemic issues, as compound challenges are addressed in manageable terms by deploying multiple, coordinated, and synergetic projects. While not explicitly the intention at inception, Stimulab and Floke have evolved from project-driven, social-innovation initiatives towards increasingly systemic, thematically driven programmes. A 2021 Stimulab report identifies an increase in complex, multi-actor projects in the programme. It further states that user-oriented and service design is no longer sufficient to address recent projects' complexity [60]. Thus, it argues for including systemic design to support engagement across sectors, disciplines, and institutions. One supplier identifying a recent Stimulab tender as a 'transformation' project references transition management [11] and Mission approaches [72] as appropriate perspectives. Similarly, a distinct course change of Floke is observed in the shift away from a consumer and end-beneficiary orientation of early initiatives. While tackling a core consumer aspect of unsustainability in current systems, it became apparent that engagement with structural issues, such as business logic, infrastructure and actor dynamics, was critically limited. In addition, in specific domains, such as the construction industry, the interconnectedness of systems is apparent. Responding to these influences, Floke is now distinctly programmatic in its approach in that grand challenges addressed are spun out as multiple, strategically aligned projects. A similar evolution in thematic orientation is observed through Stimulab's adoption of the so-called *Livshendelser* concept, which could be translated to 'Life-events'. Such framing was a substantial step beyond connected innovation towards a more systemic perspective on public service offerings and digitalisation innovation.

5.2. Process and Methodological Rationale

Both programmes adopt an overarching approach of phased, divergent-convergent [88] innovation processes. Its origins are attributed to Banathy's seminal work on systems innovation [13], with additional links to Osborn and Parnes with their *Five Diamond CPS model* [93]. The ubiquitous *Double Diamond* process model [89] is a more recent expression of divergent-convergent thinking. However, scholars argue several inherent shortcomings of the model, critiquing the over-simplification of innovation processes in complex environments. The linear representation could also be misinterpreted as a sequential gateway model commonly found in output-oriented processes, i.e., design and engineering [63]. It should be noted that the Double Diamond has seen multiple revisions, addressing some of the critiques and expanding and adjusting the original framework to include systemic- and complexity aspects. The Stimulab programme argues for an additional third sequence at the project start. An extensive diagnostic phase to orient the problem statement towards real user needs, reducing the risk of addressing symptoms and not root causes. Suppliers' project proposals must commit to this *Triple Diamond* process of the Stimulab programme. Such an obligatory, pre-defined alignment is helpful in risk reduction and a means to qualify the methodological competence of suppliers. However, experiences and feedback in the programme have identified the risk of unfortunate dynamics in which such requirements are met in a prescriptive manner at the bidding stage for legal reasons. While in practice, different approaches are implemented by the suppliers.

The Floke programme was conceived as an open innovation, multi-actor process. The innovation approach would enable organisations across sectors to co-develop new business and value-generating opportunities in addressing societal challenges [82,94]. Its divergent-convergent approach directs attention to macro-drivers as a source for insights that can inform innovation concepts co-designed in collaborative efforts by the participants. As such, it combines key elements from *sensemaking* [85,86], sustainability-oriented innovation [23], and *business modelling* [84,95] in a designerly innovation process.

5.3. Stakeholder Identification and Inclusion

The importance of multi-stakeholder inclusion and alignment in systemic change is well argued from systemic innovation and transition perspectives [11,66,96,97]. Such considerations are reflected in cases with both programmes explicitly arguing the need for participatory processes, including stakeholders across traditional sectoral and organisational boundaries. However, the Floke process proposes a highly ambitious approach to stakeholder inclusion: adopting a *Quadruple Helix framework* [68] for identifying actors and stakeholders as participants in advanced co-design activities. A Floke pre-project is initiated to investigate and scope a challenge with an independent knowledge partner (*Academia*) that, in turn, becomes a means to map out relevant actors (*Businesses*), governing institutions and policymakers (*Government*) and civil organisations/NGOs (*Society*). The resulting Floke project may consist of up to 25–30 participants representing a diverse set of perspectives, distributed along a value chain or networked complex, and as such, aligns closely with arguments made in the literature on SOI in the socio-technical perspective [45].

Less attention is present in the programmes to the boundary discussion, and little is formalised in the process or method for stakeholder selection regarding risks, biases, and blind spots. This is regularly addressed in the Systemic Design literature, such as variety deficit, which could lead to critical weaknesses in scoping [37] (p. 26). The Stimulab process can address such issues by re-scoping when concluding the initial diagnostic phase. Furthermore, continuous user and stakeholder involvement are explicitly argued as fundamental to the Stimulab approach. The Floke process is equally ambitious; its co-production approach is considered the most integrated and demanding participatory form, going beyond the co-design in that participants are expected to be heavily involved in creating content and outputs for experiments and solutions [70].

5.4. Establishing Learning Processes, Evaluating, and Monitoring

Continuous monitoring and learning are central to supporting sustainability transitions, albeit highly challenging in such a complex environment. Monitoring would include oversight of the overall progress of a systemic programme and its projects and the dynamic development of niche-level and macro events that would emerge within the extended time frames of transition initiatives [11] (p. 17). In addition, monitoring of the systemic programme itself must be considered; This includes network activities and behaviour of actors, but also a continuous evaluation of actions, goals, and interventions that might have been agreed upon. Moreover, an additional layer of complexity is added, as any systemic intervention in the socio-technical perspective will infer learning about changes to social behaviour and models [53], including that of organisations and institutions and individuals. Thus, transition management and systemic innovation strategies argue for integrated, explicit, and formalised learning processes emphasising *"Learning-by-doing and doing-by-learning"* [11] (p. 81).

Both Floke and Stimulab show evidence of extensive revisions to both programme structure and methodological approach from 5+ years of evaluated experience. However, a fundamental differentiating factor between the two regarding learning is how process facilitators are integrated. In Floke projects, facilitators are recruited within the parent organisation by internal selection criteria (domain competence, availability, and experience). Thus, learning cycles and adaptability of the methodology can be both rapid and reflexive [98]. Furthermore, learnings are easily captured within the organisation, as most employees have experience with the programme. However, no integrated routine was found to structure and disseminate such knowledge besides ad hoc de-briefs and sporadic workshops evaluating the programme. Stimulab, on the other hand, is subject to public procurement processes, in which suppliers can answer a two-stage competitive bid for each project call. The competing suppliers propose teams and process plans in alignment with the project description. As discussed earlier, such prescriptive formats may impair the suppliers' motivation to explore novel and experimental approaches [99,100] and omit real concerns drawn from previous knowledge and experience from earlier Stimulab projects. Thus, the programme must be vigilant in mediating such risks by gathering learnings beyond the programme organisation from suppliers and project owners, fostering transparency and openness.

The nature of public funding makes dissemination of learnings integral to Stimulab, as it is expected to generate transferable value to public-sector actors at large. Thus, learning processes are, to a significant degree, formalised and structured. Extensive Stimulab programme reports have been published, collating key learning spanning several years and projects, leading to revised project conditions and frameworks.

Revisits of initial scope documents as an evaluative, risk-reduction measure are present in both programmes. In Stimulab, the output of the projects is redefined based on insights from the diagnostic phase. This phase concludes with revising the problem statement, allowing the project to revisit hypotheses and re-scope the project and its priorities. The innovation brief of Floke pre-projects includes a preliminary scope of what could be described as *innovation intent*. This document then acts as an onboarding mechanism for actors and stakeholders, providing a shared knowledge platform that is revised and aligned with participants at the main project start. However, in practice, such knowledge and learning platforms are rarely revisited and revised collectively throughout the projects, contrasting with their suggested importance in the literature [11] (p. 98), [50] (p. 11).

5.5. Addressing the Landscape/Strategic Level

The socio-technical theories' landscape level (macro) relates to the larger environment where the transitions occur. Hence, it involves phenomena and issues on a societal/global scale, i.e., climate change, globalisation, international agreements, deep cultural patterns, and macroeconomics [26]. Landscape changes are predominantly slow and long-term, including the factors that may enable them. Moreover, they are not subject to change by individual actors in the short term. Therefore, engagement with this level is centred around orientation, long-term visioning, and strategising in the transition literature and the SIPs. These foci are reflected by systemic design perspectives included in the combined framework. As grand challenges exist on a continuum (Figure 1), scoping of systemic intervention must orient itself to the current landscape's macro trends. Gaziulusoy and Ryan identify several roles of design in such strategic orientation, including "*Systematising problem framing*" and "*Solving methodologies dealing with wicked problems*" [49] (p. 1305). Accordingly, Pereno and Barbero's framework suggest that design tools, such as *double-flow scenario methods* and *MLP design model*, are applicable to "*collectively identify problems, build alternative visions and establish the strategies required to implement them*" [51] (p. 125). However, such phased organisation of design tools may be contrived, as *Gigamapping* [101] would also be helpful for strategic landscape orientation purposes.

Generally, one observes numerous designerly approaches by the Stimulab and Floke facilitators for engaging with the macro level. Visual mapping is extensively used for both orientation and diagnostic purposes. Commonly facilitated as collaborative processes, their primary purpose is identifying the interconnectedness of issues and opportunities within the systemic challenge [101] (p. 250). These approaches are commonly conducted on physical print formats and allow dialogic exploration, including multiple stakeholders with little training. Furthermore, broad investigations into trends and macro-drivers are conducted as intermediary steps towards scenario generation. Such "*analysis and synthesis of different knowledge forms . . .* " [49] (p. 1305) contribute vital insight to the project group when engaging with subsequent future processes. Hence, such explorations include socio-political developments distinctively present in Stimulab, where projects are anchored in overarching policy processes that concede current governmental white papers and ministerial implementation strategies.

Visioning and futuring [102] are instrumental in establishing systems-level ambitions. In Floke, such vision narratives are initially synthesised from expert interviews and scientific contributions by the knowledge partner, from which an innovation brief is developed. It acts as a call to action for actors and stakeholders that, in turn, collectively engage with futuring processes in the subsequent innovation project. In the Stimulab, a Missions approach is expected as a central conceptual foundation for the projects. Therefore, a mutual narrative is vital in aligning the stakeholders' visions and ambitions. Such futuring (foresight) is closely aligned with the Missions approach through anticipatory innovation [72] (p. 807).

5.6. Addressing the Regime/Tactical Level

The particular attention directed towards multi-actor networks in transition management reflects the multi-level perspective of socio-technical systems. It involves the formation and persistence of regimes [26]. The ample literature points to the importance of such networks and collaborative environments in addressing the systemic issues in sustainability challenges, [22] an approach deemed fitting with the interconnectedness of regimes (a patchwork of regimes) constituting several societal systems. The complex dependencies and lock-in of regimes are at the core of their resistance to change. As such, Stimulab and Floke are expected to construct their rationale around multi-stakeholder, cross-sectoral collaboration. In the Floke programme, incumbents and innovators (start-ups and outsiders) are expected to form new project partnerships across organisational boundaries as opportunities for shared value [82]. The potentiality of such partnerships is richly described [22] (p. 78); nonetheless, Floke emphasises the provisioning of a collaborative, safe environment for experimentation, often lacking at a regime level. As a result, innovation ecosystems extend beyond the traditional partnership that may be limited to the expected flexibility and adaptability needed in systemic innovation.

The strategic recruiting of actors identified from value chain systems in Floke is analogous to *transformative coalitions* and argues that actors could also be incentivised to help address collective challenges within industries. Described as "*partnerships of multiple actors that generate innovation through knowledge flows*", Pereno and Barbero argue that such coalitions to be supported by designerly methods and tools developed for *"active engagement of multiple stakeholders"* and include stakeholder selection and interaction maps, structured dialogic-design, and transition pathways creation [51] (p. 123). Such tools seek to encompass the dynamics of dialogic processes between actors and their interests in generating requisite variations of perspectives and innovations to address systemic challenges [103]. They are central to the Floke process and included as collaborative worksheets in facilitated workshops. An equivalent role of design is identified at the tactical *in-process* level by Gaziuluzoy and Ryan, which describes the *"facilitation of participatory inquiry, design and deliberation"* [49] (p. 1305).

Regime engagement is less integrated at the project level in the Stimulab programme, which increases tensions in boundary discussions within individual projects. However, the ambition of coherent and seamless public services in the life-events framework has drawn projects together for ad hoc knowledge exchange. Additionally, the recently adopted Missions approach challenges traditional practices in governing, organising, and managing public sector services and explicitly suggests that the output of such projects are not only solutions but portfolios of initiatives that synergistically address the more extensive, ambitious challenge in the mission statement.

5.7. Addressing the Niche/Operational Level

The concept of niche level is central to the socio-technical theory. It is described as "-*where radical innovations can emerge, and new concepts can be tested in a protected environment"* [50] (p. 8). Niche innovations and, similarly, transition experiments in transition management are seeds of solutions, practices, and structures that could ultimately emerge relevant at the regime level, replacing and reconfiguring unwanted or unfit existing ones: "*Transition experiments are iconic projects with a high level of risk that can make a potentially large innovative contribution to a transition process*." [25] (p. 176). Experimentation is thus fundamental to niche-innovation development, and critically so for market and user acceptance, increasing their likelihood to reach (commercial) scale and regime integration. The intentional germinating of niche innovation is thus subject to intentional steering in sustainability transitions to develop numerous synergetic transitional experiments and solutions or portfolios [96,104].

The innovation portfolio is central to Stimulab and Floke's programme rationale. However, two critical distinctions between the two can be found in the outputs at the project level; in Stimulab, the overarching system orientation resides with the Mission [72] (p. 805), while each project's ambition is to experiment with the solution level, with users and stakeholders. Nevertheless, a strong service-design orientation risks the output-agnosticism central to systemic challenges, as suitable solutions might call for other types of interventions or even at different parts of the systems.

In the multi-actor Floke, all projects develop portfolios; even so, strategies to coordinate and synergise individual portfolios around thematic areas or domains reside centrally in the programme organisation. Individual solution concepts are not bound to participating actors; instead, the portfolio acts as a mutual repository for the group to be engaged with, depending on individual interests, resources, strategic relevance, and similar. In Stimulab, on the other hand, innovations are inherently linked to the project owners at the onset. Thus, the programme organisation performs a central role in disseminating learning and synergising effects across the project portfolios in alignment with their mission perspective. Missions and systemic innovation share key characteristics, such as being vision-led and arguing for a portfolio of interventions. However, the nature of such innovation ecosystems (analogous to strategies for enhancing niche innovations) makes goal-setting and evaluation challenging for any systemic programme.

Floke projects are inclined towards sustainable business model innovation [105,106]. As such, it will be subject to high levels of uncertainty and challenging feedback lag in the time scope of the innovation process. Therefore, the participating actors focus experimentation around issues of value proposal and market-fit [84] at the strategic level, arguing for the designerly approach to sustainable business modelling [17,107]. The outcome being business model concepts, the portfolio's primary purpose is thus oriented towards partnership formation and decision-making in the participating organisations.

6. Conclusions

This study has investigated two contemporary systemic programmes, Stimulab and Floke, with decidedly designerly approaches to systemic innovation. A combined framework was developed, integrating key perspectives from transition management, socio-technical innovation theory and systemic design, and subsequently used as a lens to structure an inquiry into the efficacy of the programmes concerning sustainability transitions.

The framing and structure of the programmes reflect overall systemic considerations in the combined framework in a credible manner. Furthermore, designerly approaches to systemic innovation are increasingly present and integrated into the framing of projects- mirroring recent research into the role of design in such contexts. However, these advanced systemic perspectives are recent additions to the programmes, and long-term effects are to be evaluated. Several challenges at the programme level were identified in the discussion.

The compound problematic of grand societal challenges makes boundary discussion increasingly demanding for the programmes regarding project strategies and initiation. Such challenges arguably exist on long-time scales (continuums), with a consequent need for establishing continuous learning and accumulation of thematic knowledge. The relatively short project processes within the programmes (6–12 months) compound the issue as suppliers, actors and stakeholders are frequently onboarded and egress. The question arises whether such systemic insight should reside within the individual projects and suppliers, as with Stimulab, or be readily accessible throughout the innovation ecosystems of the programmes.

Intentional systemic change relies on a synergetic portfolio of interventions by diverse actors and stakeholders. Since transition experiments are frequently high-risk and resource-demanding, dissemination of learning becomes critical at the niche innovation level that constitutes the projects' main output [25] (p. 176). The substantially delayed observable effects of niche innovations at the meso and macro levels further argue for establishing innovation ecosystems as part of the programme rationale. This suggests that the programmes must address policy and regulatory ecologies to enable a protected or experimental space for the portfolios to develop and scale [50] (p. ii). This experimental nature of the programmes challenges traditional forms of collaboration and funding, revealing a tension between the need for open-ended processes and effect orientation. The open aperture approach of systemic innovation is adopted as experience shows that root causes might need to be better understood for larger complexes of challenges at project onset, which puts increasing pressure on the programmes to reliably onboard and manage expectations. Additionally- the notion of prescriptive reproduction of innovation becomes incompatible with current systems perspectives.

Finally, the inherent challenge in communicating system transition theories and strategic management is evident at several levels. Boundary discussions and project framing become challenging for programme owners and project participants. They must increasingly be understood as a recurring, re-scoping activity in system innovation. Furthermore, experiences show that the transfer of project portfolios becomes challenging, partly due to the loss of learnings generated within the project processes and the complexity of implicit organisational changes necessary for implementation.

This study does not contend that designers should practice transition management per se in Systemic Innovation Programmes but rather an investigation into how current systemic design practices may or may not readily interface with transition processes. Facilitators in such systemic programmes will likely be required to align and acknowledge governing influences of transition management in the future. In such a context, it will become imperative that designers understand how such perspectives could be integrated and nurture the essential feedback loops necessary for sustainability transitions.

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Appendix A

	ID	Document type	Title / Name	Description	Publication/ retrieval date
Stimulab Innovation Programme	#01	Print publication	*StimuLab-Brukerorientert offentlig innovasjon – råd og erfaringer fra frontlinjen*	Programme report, summary of learnings	2021-04-22 / 2021-09-13
	#02	Web page	*Veiledende bilag til SSA-O – Oppdragsavtalen*	Main document including background, description and scope	2021-04-22 / 2021-09-13
	#03	Digital document	*Konkurransegrunnlag Fase 2 - P 07-20 Starte og drive en frivillig organisasjon*	Conditions for the Stimulab tender	2021-04-22 / 2021-09-13
	#04	Digital document	*Bilag 2 Konsulentens spesifikasjon av Oppdraget*	Offer from supplier, including approach	2021-04-27 / 2021-09-13
	#05	Digital document	*Notat vedlagt endringsbilag*	Change-document, supplier project brief	2018-11-26 / 2021-10
	#06	Print publication	*Endelig rapport - Starte og Drive en frivillig org*	Final deliverable, project and process report	2018-11-26 / 2021-10
	#07	Print publication	*Starte og drive en frivillig organisasjon*	Final deliverable, solution report	2018-10-28 / 2021-10
Floke Innovation programme	#08	Digital presentation	*Floke 2016-2021 - Feedback rapport*	Programme report, summary of learnings	2021-01-12 / 2021-10
	#09	Digital document	*Byggfloken 2.0_kunnskapsgrunnlag*	Knowledge fundament for Floke project	2020-06-10 / 2021-10
	#10	Digital presentation	*Byggfloken2.0_introduksjon*	Main document including background, description and scope	2021-08-01 / 2021-10
	#11	Digital document	*Prosjektplan Bygg 2.0*	Project and process plan	2021-08-05 / 2021-10
	#12	Print publication	*Byggfloken 2.0 Nøkkelinnsikter*	Report, project findings	2021-09-29 / 2022-02
	#13	Print publication	*Byggfloken 2.0 konseptportefølje*	Final deliverable, process and evaluation report	2022-03-17 / 2022-03-25
	#14	Digital presentation	*Byggfloken 2.0 Tek Pluss Porteføljelansering*	Final deliverable, solution presentation	2022-03-17 / 2022-03-25

Figure A1. A complete list of documents used in the study.

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Article

Invoking 'Empathy for the Planet' through Participatory Ecological Storytelling: From Human-Centered to Planet-Centered Design

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Abstract: In sustainable design and innovation, appreciation of the Planet as an equal stakeholder with humans and businesses continues to rise. Yet a consistent challenge arises in that people have difficulties relating to the nonhuman and interpret the world in terms of human values and experiences. We need more practical tools to stimulate a connection, especially in its affective dimension, to the Planet and to include nonhuman stakeholders in sustainability developments. To anchor Planetary understanding and considerations, we investigate the role of participatory storytelling to stimulate a reappraisal of the needs of nonhuman stakeholders through empathy building. To posit this, we defined empathy for the Planet as a holistic relationship with human and nonhuman stakeholders. We facilitated workshops where design students, design professionals, and business stakeholders could co-create environmental stories using human and nonhuman character personas. We analyzed the personas, stories, and participants' feedback on the process experience and impact and observed that story creators experienced empathy for the Planet through projecting and blending their own emotions and intents onto the characters. We discuss, therefore, how ecological story co-creation can be a tool for self-reflection, collective sense-making, and the inclusion of the voice of Planetary stakeholders relevant for sustainable design and to drive sustainability engagement in general. This research confirms the role of stories and imagination in creating a bridge to the natural world through new, human and nonhuman, perspectives.

Keywords: storytelling; co-creation; empathy; nonhuman characters; nonhuman persona; more-than-human; post-anthropocentric; system thinking; sustainable design

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1. Introduction

Design relies on empathy for people, but what about empathy for the Planet? In sustainable design, innovation, and business, the Planet is increasingly seen as a stakeholder as important as humans and businesses (see the People-Planet-Profit Triple Bottom Line Framework) [1–3]. An example is the company Patagonia, which declares on their website that "Earth is now our only shareholder" and gives their profits to environmental NGOs. However, a general challenge in sustainability is that people have difficulty relating to the nonhuman world (animals, plants, natural ecosystems, etc.) [4,5]. This reinforces an anthropocentric way of approaching sustainability, i.e., where we interpret the world in terms of human values and experiences. Focusing solely on human needs reinforces unsustainable solution development, while considering human and nonhuman needs is necessary to shape solutions that benefit all stakeholders in the Planetary ecosystem [6–8].

Design, as a discipline (encompassing product design, service design, design research, strategic design, communication design, etc.) where the starting point is an empathy-driven understanding of stakeholders' needs and perspectives [9,10], could be the bridge to interpreting the nonhuman world and including Planetary viewpoints in sustainable developments. Could designers—in the same way empathy is utilized for human stakeholders in people-centered design—use empathy for Planetary stakeholders (the whole ecosystem of human and nonhuman entities on Earth) in sustainable design, and how?

While design is a driving force of sustainability and is rapidly developing in the material and business aspects (e.g., eco-design, circular design, design of KPIs, goals, and requirements) and the human aspects (e.g., communication design, design for behavior change for a circular economy) [11–14], the focus is on the human and the man-made, and the relationship with the Planet, especially the affective aspects, is only slowly getting considered. Emerging nature-inclusive design approaches driven by posthumanism and systemic thinking—e.g., bio-inclusive design, life-centered design, planet-centered design—call for an involvement of a larger set of stakeholders, human and nonhuman [8,15–20] and drive the development of new design frameworks including the nonhuman, or 'more-than-human' [7,8,15,21,22]. These frameworks express new relationships between humans, nonhumans, technology, and spaces. They call for a better understanding of the nonhuman and a recognition of its specificity and capacity beyond an anthropocentric view. However, the impact of the empathic, emotional, or compassionate aspect towards the nonhuman is little explored. This gap fits with a more general need to investigate the affective dimension of climate change engagement [23–25] and to develop 'soft approaches' to trigger environmental action that is becoming apparent in the field of conservation [26–28], environmental communication [14,29,30] and education [31,32]. To accelerate sustainable transformation, we need the more profound motivation that an empathic connection with the Planet could bring. Empathy for the Planet might involve different mechanisms and implications than empathy for people; hence, we need to understand ways to stimulate it, its mechanisms, its meaning, and its impact on sustainability.

Many traditional design tools that stimulate empathy are difficult to apply to nonhuman stakeholders because they often use language-based communication to connect to stakeholders and understand their experiences [2,33]. Storytelling, though, can be used as a design tool to stimulate empathy for nonhuman stakeholders because it relies on imagination to step into their shoes [3,34–36]. Stories based on end-user personas are widely used by designers to investigate and illustrate human users' needs, emotions, and behaviors and to promote empathic engagement [37–43]. In this research we take a similar approach where personas and stories express the perspective of the Planet and we explore how it can create an empathic connection. The creation of nonhuman stakeholders' personas is already being explored as a tool for designers [44,45], and is the first step of story creation. Building stories with these personas will help imagine their stance, emotions, intents and reactions along a journey, which is key in recognizing their agency and moral kinship and putting the nonhuman to equal footing with the human [3,46].

In this research, we want to answer the following questions: Can storytelling be a design tool to elicit empathy for the Planet? What are the meaning and implications for sustainable design of empathy for the Planet generated through this method?

To explore the emergence, experience, and impact of empathy for the Planet, we designed a method where participants co-create stories based on Planetary (human and nonhuman) personas. The stories are environmentally themed, but the type of character (human, animal, vegetal, inanimate, metaphorical, etc.), the type of story arc, as well as the strategy to create empathy of the Planet are completely open. We use storytelling as a participatory process instead of the more classical teller/receiver approach because, while well-crafted stories can have a profound impact on an audience, e.g., to trigger pro-environmental behavior change [47,48], a specific story only resonates with a specific audience. Rather, we involve participants to create in a non-prescriptive way characters and narratives that have meaning to them as individuals and as a group. As a participatory tool, story making is known to stimulate multidisciplinary collaboration, idea and emotions sharing, new perspective taking, out-of-the-box thinking, and collective sense making [41,43,49–51]. We applied this method in four workshops with design students, professional designers, and business stakeholders. By looking at the created stories and feedback from the participants, we investigate how the method is used by designers and business stakeholders, their experience of the process, and the impact it has on their emotions, perspectives, and behavioral intentions. Based on these results, we can assess the method and attempt a definition of empathy for the Planet. The learnings on participatory ecological storytelling could be converted into a design tool to be used in different contexts (i.e., in design/business environments or with general audiences).

This article starts with a review of relevant literature on nonhuman stakeholders and empathy for the Planet in design, literature, and communication, and on participatory story-based processes that support the rationale for building our participatory ecological storytelling method. In the Section 2, we describe the workshop process and the protocol for data collection and analysis. In the Section 3, we show the analysis of the stories in terms of characters, story themes, and endings, and the summarized participants feedback about the way they created empathy, their emotions, their experience of the process, and how it impacted them. Finally, we discuss the findings to infer the empathy-creation mechanisms of participatory ecological storytelling, the positioning of empathy for the Planet and the potential implications of the method for design practice, concluding with the limitations of the study and its outlook.

1.1. Framing of Empathy for the Planet

Empathy in its broad sense refers to taking the perspective of another and is viewed as a multidimensional, i.e., cognitive and emotional, phenomenon [9,52]. It is a vastly studied concept in aesthetics, sociology, and psychology, with its ambiguities and controversies [46,53].

Empathy is connotated as a relationship with the individual and the human, thus associated with human-centrism rather than post-anthropocentrism (i.e., considering humans as equally important as other entities in the universe) [54]. However, it is good to remember that the term empathy initially related to an emotional connection to a nonhuman entity: the word, a translation of the Greek *empatheia* meaning "passion, state of emotion", was coined in 1858 by the German philosopher Rudolf Lotze to describe an aesthetic appreciation and projection of human feelings onto the natural world and inanimate objects [53]. In this research, we want to avoid creating an a priori dichotomy between the empathic experience for the human and the nonhuman. Nonhuman may refer to nonhuman animals, other living entities such as plants or fungi, and "things" ranging from rocks, landforms, water bodies, natural ecosystems, to man-made objects [7,8,55]. The human-nonhuman dualism reinforces the anthropocentric bias where the nonhuman is not considered as moral kin, which creates a psychological distance to the animal and natural world and contributes to an attitude of instrumentalization of this world [3,56]. Instead, it is important to develop the ability to think flexibly across the human-nonhuman divide to recognize the ethical needs of both communities [35]. In posthumanist studies, the boundaries between human and non-human are blurred [6,7,57]; one needs to value the "sphere of otherness" while avoiding a sharp demarcation [56]. Quoting the ecological storyteller Anthony Nanson, there is a way to consider "nature as a whole", to "reunite the individual and the collective, with a complexity composed of the intricacy of senses, behaviors, and relationships of the individual entities in the Planetary ecosystem" [58]. This links to the notion of interrelatedness, a sense of relationship with the self, others and the nature. As the writer Alida Gersie reflects: "In order to be 'ecologically sensible' we need to think and feel relationally" [50]. This idea of developing and valuing relations between entities is also fundamental to systems thinking: designers must acknowledge that behaviors, emotions, experiences of actors and their environment in a system are influencing each other, and that agency is both individual and collective. Hence, we frame empathy for the Planet as a holistic notion including empathy for human and nonhuman, individually and as a collective ecosystem. We believe that this framing is necessary to enable horizontal relationships and a respectful dialogue where human and nonhuman are considered equal. The notion of empathy for the Planet can be found in the field of compassionate conservation, with Batavia describing it as "an emotional experience of interdependence and shared vulnerability" [27]. It also emerges in education [59–62], where Dolby et al. use the term "new empathy" encompassing empathy for humans, animals, and the planet.

With this definition in mind, we will summarize in the next section the current positioning of empathy for the planet in design practice and the tools to stimulate it.

1.2. Empathy for the Planet in the Design Practice

Empathy is a key element in the practice of design since the rise of Human-Centered Design in the 1990s and is seen as an enabler of meaningful product and solution innovation and development [9,10,52,63]. In this context, empathy is both an explicit step of the design process and an ability and emotional state of the designer [9,10]. Empathy helps designers to comprehend or imagine the feelings, stance, and perspective of the subjects they design for (cognitive empathy), to emotionally connect and identify with them (affective empathy), and it motivates to solve their problem, relieve their suffering, or enhance their wellbeing (empathic concern, also called compassion or motivational empathy) [17,64–66]. Designers use empathy to inspire and drive their design decisions, build experiences that are relevant for users [9,52,67] and to keep an active, respectful, and open attitude towards them [10]. For these reasons, we see empathy as a natural entry route for the integration of nonhuman stakeholders through consideration of their needs and perspectives.

The role of empathy in design is subject to discussion. Empathy is too often generalized as an emotional connection for the other and confused with sympathy (which can be summarized as feeling concern for the other) [63]; an overemphasis on connecting emotionally to users may be detrimental to the design process if it leads to overwhelming emotions and affects rational thinking [52]. Furthermore, because empathy for other human beings is facilitated by similarities of thinking and feeling and by one's judgement on their situation [63], there is a risk that designers understand users through their own perspectives, memories, and experiences and project their thoughts and emotions onto the user, hence biasing the design research output. On the other hand, this process of self-reflection, i.e., recalling explicitly one's own memories and experiences, can also be beneficial for connecting and empathizing with users [52]. The exact extent and nature of affect sharing in empathy is a subject for debate, but there is consensus that it requires emotional literacy (i.e., the ability to understand and express one's own or another's emotions) [50]. Finally, empathy building in the design process is influenced by the quality of the process, where incomplete observation, personal bias, or ignorance can lead to the omission of relevant information [63]. Designers must make conscious decisions reflecting their design ethics and desired social impact on their strategy to gain empathy with stakeholders and the extent to which their own values are embodied in the process [63].

Classically, in the people-centered design process, empathy is built while gathering knowledge about and connecting with users through design research methods such as observation, interviews, context mapping, journey mapping, and while simulating and imagining experiences through, e.g., prototypes, design probes, empathy simulators, storytelling, role-playing, and bodystorming [9,33,52,63,68–70]. Designers also use storytelling techniques, including personas, scenarios, and storyboards, to empathically communicate users' experiences to other actors involved in product or solution design and development [10].

These tools and methods apply primarily to human stakeholders; involving nonhumans through traditional design research methods is practically limited, which results in a inequal role in the process [8,63]. Leveraging animal studies and the emerging field of plant psychology, designers are exploring methods and the associated ethics to include nonhuman animals [44,71–74], plants, and other nonanimal stakeholders in the design process [8,45,75]. The impossibility to communicate and understand through language and to directly compare experiences with the nonhuman world limits the development of cognitive empathy during design research. This can to a certain extent be compensated by knowledge of the nonhuman's natural history and emotional literacy [2], but design tools to develop empathy for the nonhuman are still lacking.

Design research tools based on imagination, such as storytelling, may remain effective in generating affective empathy with the nonhuman. Stories have the capacity to facilitate taking different perspectives through the story characters and engaging with alternative, unknown environments and experiences [3,34,70,76]. Stories "make familiar the unfamiliar" [36]. For example, new approaches for design research with the more-than-human explore fictional dialogues with objects and artificial intelligence to understand their perspectives and initiate a co-design process [76–78]. These narratives bring to the surface possible opinions and intentions of daily objects about their use and misuse—a critical eye on the design that opens new possibilities for designers. Taking nonhuman perspectives in stories is not common practice in design but is frequent in literature. This type of story has the potential to expose designers to different environmental understandings, serve as a point of comparison between the human and nonhuman worlds, and stimulate new ways of thinking, empathic connections, and behaviors [79]. To extend the known story-based design toolset to Planetary stakeholders, the method presented in this study leverages learnings from literature and environmental communication studies related to the notion of empathy for the Planet, which are summarized in the next sections.

1.3. Empathy for the Planet in Stories: The Role of Imagination, Anthropomorphism, Human Bridges, and Identification

Storytelling is a powerful tool to stimulate empathy and its co-drivers: interrelatedness and emotional literacy [50]. In environmental studies, stories are a known tool to rearticulate complex relationships between humans, nature, and technology, to connect the personal and the social, the local and the global, and to link causes and effects [58,79–82]. Environmental narratives can stimulate pro-environmental engagement by communicating and making easy to remember facts, but also by shaping beliefs and co-constructing meaning in new relationships with each other and with the world [58,83–87]. To engage, these narratives must translate the inherent uncertainty and complexity of the topic into a positive outlook while making the audience curious about the challenges and empowered on the ways to act [29,30,83,88,89]. Storytelling, with a focus on playfulness and empathetic connection, is widely used by brands to communicate about the environmental impact of products, to change people's preconceptions about second-hand or eco-products, and to promote eco-friendly consumption and behavior [90–92]. Climate change documentaries using empathy creation and imagery have become a popular tool to engage audiences and stimulate action on climate change [31].

Empathy in environmental narratives is closely linked to imagination: imagination favors projecting oneself in another situation [10]. Because humans cannot fully apprehend the nonhuman, imagination has an explicit role to play in building our perception of the environment [34]. Furthermore, imagination in climate fiction helps people make sense of the environmental challenges spanning large timescales and geographical locations and envision radically different social, political, and economic futures [87,93–96].

The main line of thinking in post-anthropocentric narratives is to move away from the traditional story canon where humans are the central narrator and open to nonhuman characters treated as sentient beings capable of agency [3,46,93,96]. Interestingly, a framework developed in animal studies—that can be applied to all Planetary stakeholders—describes four characteristics influencing the creation of empathy: agency (ability to move, eat, play, groom, etc., and present social and moral behaviors); affectivity (ability to show emotions); coherence (being easily understood as animal-like with arms, legs, body, and face—eyes being particularly impactful); and continuity (spending time with another increases understanding and empathy towards the other) [2,97]. The assignment of these characteristics to nonhuman story characters will facilitate the creation of 'narrative empathy', a concept in cognitive literary studies describing the "imaginative process whereby readers temporarily adopt the perceptual, emotional, or axiological perspective of a fictional character" [70].

A mechanism to promote empathy for the nonhuman world is anthropomorphism, i.e., the assignment of human characteristics and purposes to nonhuman entities, and it has been shown to motivate conservation action [70,98,99]. Anthropomorphism is widely used in traditional stories, fables, and children's stories, and in marketing. It helps to perceive nonhumans not as passive objects but as active individuals with particular perspectives, values, and motivations worthy of moral consideration, especially when similarities are found between nonhuman and human moral behavior [100,101]. It can bridge a psychological barrier towards entities that score low on the agency, affectivity, coherence, and continuity scales. For some, anthropomorphism is a condition for building empathy for nonhuman characters or narrators in a story [102]. For others, there is a risk of reinforcing anthropocentric bias [103] and triggering 'false empathy' (the incorrect projection of personal experiences and the incorrect belief that one feels the suffering of another without cognitively understanding the other) [33,58,70]. While these risks are to be kept in mind, there is a line of arguments supporting the idea that the mere attempt of imagining and representing nonhuman perspectives is beneficial to revisiting the respective positions of the human and nonhuman worlds and to initiating new relationships based on consideration and respect, even if the nonhuman perspective is not accurately recreated [3,34].

Another route to building empathy for nonhumans is the use of human bridge characters, or "human proxy", that are role models in expressing emotional responses and altruistic behavior for nonhuman subjects [47,102]. Human bridges can be narrators, existing human protagonists (such as cameramen in ecological documentaries), or fictional characters. The story receivers partially experience the emotional and cognitive states of the human bridges, which breaks down "the invisible wall between viewers and animals" and emotionally engages the audience "with a world they have become distant from" [102]. It is interesting to think that designers, who often take the role of a 'bridge' between end-users and other stakeholders by carrying end-users' stories, could be a 'human bridge' to the Planet in sustainable product or solution development.

Identification (the cognitive and emotional process of putting oneself in a character's shoes) with story protagonists is linked to empathetic engagement and confronts story receivers with the consequences of climate change and pollution that the protagonists might face, makes different environmental realities and perspectives closer and more personal, and facilitates imagining alternative futures and personal transformations [80]. Identification is favored by imagination, narrative exposure, and similarities in demography, past experiences, viewpoints, and goals [104]. Therefore, a variety of characters and narratives that illustrate different belief systems and views on climate change will facilitate identification. A participatory story making process where participants can choose the type and features of the story characters will favor the creation of a variety of characters; the choice of the character and the expression of their nature through the story making process may reveal the beliefs, values, and emotions of the story creators.

1.4. Ecological Self-Narratives

Today, environmental communication can often appear too factual, not attention-grabbing and not emotionally engaging enough [29,30,105]. It faces the challenge of a "narrative deficit" preventing people from framing themselves in terms of climate action [83]. Frames are unconscious mental models that people use to interpret the world around them and evaluate new facts presented. If the facts do not match one's frame, they will be perceived as senseless and ignored; if the facts fit into existing mental frames, people are more likely to recognize, accept, and engage with them [106]. Narratives can connect facts to one's frame by appealing to values, emotions, concerns, pre-existing cultural narratives, and metanarratives about the world [83]. Cognitive psychologist Bruner talks about the "narrative mode of thought", which enables the organization of everyday interpretations of experiences, events, places, people, etc. in story form [107]. However, the perception of environmental challenges and climate change is highly personal; it is influenced by personal experience, beliefs, and perceptions; ideological polarization; psychological distance; gender; age; nationality; social identity; internal dimensions such as ethics and altruistic or egoistic traits [23,24,29]. Environmental communication must match their message and strategy to a given audience, which is challenging because of the practical cost of identifying and researching the audience [14,108,109].

To answer the difficulties in creating targeted narratives, there is a growing interest in shifting environmental communication from a traditional top-down, story teller-receiver approach to a participatory process where audiences dialogue, discuss multiple interpretations of a story, and develop narratives [50,51,58,83], and to develop platforms stimulating such interactions [14]. Participatory storytelling allows for the direct engagement of the audience, and the audience creates meaning through a narrative in line with their frame while creating a safe space for exchange that opens to other values, experiences, and perceptions [83,94]. Self-narratives (the way individuals translate relationships and events from their lives into stories that can be retold to themselves and others) and personal values are expressed and clarified through the auto-investigative potential of story creation; stories are used in socio-ecological research to help us reflect on and rework our knowledge and experiences, our interactions with the environment and with each other, to formulate our beliefs, our identities, and our values, to "reveal things to us that we know but didn't know we knew" [58,110,111]. For example, students were asked to write their personal life stories in relation to climate change, and constructing their personal biography impacted their self-perception and the type of goals they set for themselves [81]. Storytelling and story making also stimulates emotional literacy, potentially enhancing the auto-investigative impact and the ability to empathically connect to others [50].

1.5. Ecological Collective Narratives

Through connectedness, comparison, and overlaps in perceptions, values, and motivations, stories stimulate the emergence of social narratives and shared values [112]. Stories have been shown to be carriers for collective imagination of different futures [79,113], for the development of collective efficacy (the thought that one has the ability to impact) [89] and "ecological identities" (a way to relate to the world and to others grounded in memories and feelings about the environment) [81,82].

Participatory dialogues such as story making enable the expression of diverse individual voices but at the same time connect personal and group actions to the bigger picture of environmental challenges, which stimulates both an individual and a collective, entangled response [30,83,114]. Participatory storytelling connects self-narratives to social narratives; it expresses self-focused values to make communal values emerge [3]. Reason et al. elaborate on the idea that collaborative storytelling and retelling enable the participants to add their own layers of experience or values to the story, similar to the traditional retelling of stories, and contribute to a communal and appropriated knowledge, which they call 'storyknowing' [115]. This links to quantum social theory, which promotes a participatory approach to change supported by subjective meaning and metaphors to empower individuals and groups through a transformed sense of collaborative agency [114]. Story creation has transformation potential on an individual level by being a "symbolic act" opening a path to transformation [58] and collectively by taking the role of a "boundary object" [49,116], a "shared intellectual space" [117], or a "translation tool" [51] between story co-creators from multiple disciplines.

There are multiple examples of dialogue and co-creation around environmental narratives targeted at engaging and stimulating audiences. Shaw et al. designed a Narrative Workshop methodology where citizens develop new stories based on their values and identities to engage in discussions about climate change and its policies to shift the climate change story "from a scientific to a social reality" [30,118]. The Stories of Change project engages individuals and groups in energy transitions through play and reflection upon stories exploring the relationship of humanity with energy [117].

Collaborative filmmaking on environmental topics has been shown to trigger personality development, change agency, and a sense of responsibility [119]. Rotmann reports on using a fairy tale-based 'story spine' in behavior-change practitioner workshops to elicit stories from diverse stakeholders and help develop better interventions that change citizens' energy-use behavior. These works contribute to the theoretical understanding of the processes that connect individual engagement to the societal change needed to address environmental challenges and to the development of practical methods to trigger the social dimension of public engagement [84].

In the above work on individual and group story making, the "voice of nature" is not represented, and the nonhuman realm is not included as an agent of change. Nevertheless, the openness, connectedness, and sense of collective efficacy initiated by these participatory processes are a major step towards including new, nonhuman, stakeholders. The references in terms of participatory, nature-inclusive storytelling are the extensive books by Nanson and Gersie et al. that describe how storytelling can create strong and intimate bonds between story tellers, listeners, and the natural world [50,58]. They use inspiration from traditional folktales and often use animals, plants, trees, or metaphorical or mythological characters that represent the Planet. They advocate for oral storytelling and give much attention to the space in which the storytelling act takes place—preferably nature—as storytelling favors connectedness with the immediate environment. Toivonen et al. show in their 'Storytalk' that dialogue around narrative experiences helps conceptualize human-nonhuman relationships and ascribing agency to the nonhuman [35]. Participatory storytelling, by involving "many tellers and hearers" [96] and including the Planet through characters, can blur the demarcation between 'spheres of otherness' [56] along the lines of complex human-nonhuman networks and of the reassessment of individuality in posthumanism [3,56,96].

In the design context, there is a need for such a creative, collaborative, and nature-inclusive process [8]. Participatory ecological storytelling can be such a method, stimulating the construction of collective narratives, where 'collective' not only includes the human group but also (part of) the nonhuman world. Such collective narratives may influence the way designers and their (human) stakeholders work together and the way they include the Planet in sustainable developments. This study may help clarify the influence of the participatory aspect (i.e., listening, sharing, and building upon others' perspectives) in connecting individual voices and including the voice of the Planet.

1.6. Principles Guiding Our Participatory Ecological Storytelling Method

The process presented in this paper was built based on prior hands-on experience with participatory storytelling with end-users as characters [49] and includes learnings from the previously discussed literature in order to extend to nonhuman characters. As a result, we identify and define four principles important to designing the participatory ecological storytelling workshop. These are:

(1) Planetary character: the character of the story can be human, animal, vegetal, natural, object, spiritual, metaphorical, etc., singular, a group, or an ecosystem. The workshop participants are free to choose the type of character and whether to use anthropomorphism or not. The character's journey in the story illustrates the story theme—the "main message"—related to environmental challenges or sustainable solutions. The characters are developed through a Planetary persona template.

(2) Character depth: building granular character personas with motivations, history, a rich inner world, and positive and negative sides is key to creating compelling characters [49]. It enables imagining their reactions and decision rationales along with the events of the story, which is essential to assigning them narrative agency.

(3) Playfulness: participatory storytelling presents similarities with play in its cooperative, non-hierarchical, instinctive, and improvised dynamics and in overcoming divisions of nature and culture [3]. Such dynamics yield original ideas and the expression of tacit knowledge (i.e., knowledge gained through personal experiences) as story creators

encourage each other to be creative, expansive, humorous, and honest [38,49]. The intrinsic experience of building the story and engaging with others, the character, and their world is more important than the resulting story [7]. Participants are encouraged to build on each other's suggestions, to try, to be imperfect, to use humor, and to share personal experiences.

(4) Open plot: we do not enforce the use of antagonists or villains or pre-defined story arcs such as the Campbell heroes journey in order not to nudge the stories into a conflictual story canon that may reinforce the human/nonhuman antagonism [3]. The story structure is as open as possible while using well-known narrative components to make it easy to create the story [120]: participants are guided to create story arcs with a beginning, a middle, and an end, with the middle part dynamized by the struggles of the main protagonists.

2. Materials and Methods

2.1. Structure of the Workshops

This paper presents the results of 4 participatory ecological storytelling workshops with different groups:

- Workshop 1 involved a group of 31 students in the first year of their industrial design education at a Dutch university, was conducted online, and took place in January 2022. The students were taking a course aimed at developing their critical thinking, and the workshop was an element of that course.
- Workshop 2, which involved 10 participants, was conducted in real life during an international design conference in July 2022. The participants were professionals or senior students (Master's, PhD) in the field of design and art.
- Workshops 3 and 4 were conducted at a large multinational in February 2023 with 25 people each, with roles in marketing, business, design, and innovation.

In this paper, we will refer to the first group as "design students", the second as "designers", and the third as "business stakeholders". For all workshops, the participants volunteered to join, demonstrating a prior interest in the topic of storytelling and/or sustainability.

The details of the workshops can be found in Table 1. The workshops were facilitated by the authors of this paper. All workshops started with a 30 min–1 h introduction and discussion, followed by 1.5–3 h exercises, including persona and story creation and sharing, and a final discussion. Workshops 1 and 2, which lasted 3 and 4 h, had an extensive story creation exercise. When designing workshops 3 and 4, which lasted only 2 h, we decided to focus on the persona creation exercise and keep the story creation shorter. The reason is that in workshops 3 and 4, we wanted to give the participants, mostly non-designers and therefore generally less familiar with persona creation, more time to immerse themselves in the persona creation exercise. For this reason, we chose to do the persona creation individually and with more extensive questions than in workshops 1 and 2. In the rest of this paper, we will refer to workshops 1 and 2 as "story-focused workshops" and workshops 3 and 4 as "persona-focused workshops". Besides this difference, there were small variations in the workshops, such as total duration, size of groups, warm-up exercises, online/real life format, ways of sharing the stories.

2.2. Data Collection and Analysis

The data used for this study consists of the stories written by the participants and the feedback given by the participants in individual questionnaires after the workshops. In workshops 1, 2, and 3–4, respectively, 10, 3, and 15 stories were created (n = 28), and we collected the feedback of 22, 8, and 21 participants (n = 51). Four illustrative stories and one persona can be read in Appendix A.

Table 1. Overview of workshops processes.

<table>
<tr><th>Step in Workshop Process</th><th>Story-Focused Workshops</th><th>Persona-Focused Workshops</th></tr>
<tr><td>Introduction</td><td colspan="2">We presented a recap of storytelling theory basics (narrative transportation, role of empathy and mental imagery, basic story arc structure, building blocks for a story character, tips for creative writing) [121,122] and high-level examples of ecological stories (wildlife documentaries, fictional movies, personal stories, traditional tales) [47,50].</td></tr>
<tr><td>Persona creation exercise</td><td>Collectively (in groups of 2–4), participants were asked to discuss and write down:
- how the persona looks
- their qualities and flaws
- what they love and dislike</td><td>Individually, participants were asked to think about their character and to write:
- how the persona looks, moves, transforms
- the sounds they make
- their qualities and flaws
- their past and memories, how it shaped them
- what they love and dislike
- their social circle, what/who is around and how that makes them feel
After the exercise, participants in groups of 3 shared their personas (an active listening exercise) and picked one for the story creation.</td></tr>
<tr><td>Story creation exercise</td><td colspan="2">Participants in groups built the story arc for their persona by filling in keywords or short sentences in a story template. The template structures the story into a beginning, a middle and an end:
- The beginning includes questions about the wanting of the main character (their drive for the story) and the context of the story (encouraging use of local names of animals, plants and land features, description of looks, smells, feelings and sounds).
- The middle stimulates imagining the obstacles that the character meets on their journey, their possible struggles, successes, discoveries, and the companions on the journey.
- The end of the story asks about the outcome of the journey, the changes experienced by the character or their outlook.</td></tr>
<tr><td>Sharing</td><td>Stories were written as a short text and in workshop 2 were also verbally shared.</td><td>Stories were written as a postcard from the character to humans.</td></tr>
<tr><td>Closure</td><td colspan="2">An open discussion was facilitated where participants shared their experiences and learnings during the story creation and reflected on possible benefits of the method for their line of work.</td></tr>
<tr><td>Total workshop duration</td><td>3–4 h</td><td>2 h</td></tr>
</table>

The stories were classified along type of heroes (the main protagonists: human, animal, vegetal, mythological, other) and companions (i.e., protagonists who have a positive relationship with the heroes and an active role in helping them on their journey: human, animal, vegetal, mythological, other), themes in the stories, and endings of the stories (positive/negative). The human, animal, vegetal, and mythological character categories came from the classification of the ecological story examples presented in the introduction to the workshops. The stories were analyzed by the first author of this paper using a thematic analysis approach to identify recurring themes. The stories were decomposed into a series of events (3–10 per story), including the climax/ending (the final, emotionally loaded action of the story). Themes emerged from the stories by summarizing each event or group of events as an action or intention of action carried out by a character. Summarized events across stories were clustered by similarities in character and action, and sub-themes emerged. The sub-themes were grouped into main themes. As a result, each story contains 1–5 themes. Endings were classified as positive if the climax/ending moment presented an outlook that was positive, joyful, hopeful, or open for positive developments, and negative if the conclusion expressed helplessness, pessimism, or figured the death or fatal wound of the main characters.

The questionnaires consisted of a series of semi-open questions asking the participants about (1) their approach to communicating empathy in their persona and story, (2) the emotions it evoked, (3) their experience of the process in the workshop, and (4) the possible changes or motivation triggered by the process, in line with our research question. We used these four topics to classify and analyze the results. First, quotes from the answers were collected in relation to these four categories, and each quote was coded to be assigned to a category. Within each category, we used inductive coding to assign to each quote a sub-code describing the type of approach for empathy creation for (1), emotion for (2), co-creation benefit, enabler, or difficulty for (3), and change (awareness, intention of action, or none) for (4). The sub-code structure was refined when reviewing the first 30% of the quotes of workshops 1 and 2, and then those from workshops 3 and 4, to ensure accurate capture of data themes. The rest of the data were deductively coded according to the finalized coding structure. The quotes were grouped by sub-code and summarized with minimal rewording for each category.

3. Results

3.1. Story Characters

The participants chose hero characters that were animals (fishes, turtles, other marine animals, squirrels, monkeys, sloths), vegetal (trees), inanimate natural (oceans, sky, lands, sand, clay), a bacteria family, a man-made object (a wind turbine), and a mythological creature (a yeti); see Figure 1.

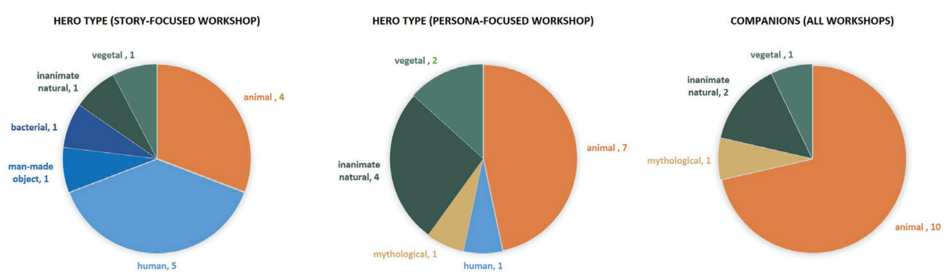

Figure 1. Repartition of the types of heroes for story-based workshops (**left**), persona-focused workshops (**middle**), and companions for all workshops (**right**). The number next to the category indicates the number of stories that display the category.

The animal and tree characters were anthropomorphized and given traits of innocence, friendliness, sweetness, and were family oriented. More specifically, story creators chose animals that were likeable or known from existing stories (like Nemo or Chip 'n Dale). As one participant said, *"By making the animals cute, people might feel more like they want to protect them"*. Natural elements such as oceans and sky were assigned traits of grandeur, generosity, sentimentality, and emotionality (see *the Great White Ocean* persona in Appendix A), with heightened emotions manifesting through water movements and weather.

The human heroes were, at the beginning of the story, self-centered, pleasure-seeking, and ignorant. The bacteria, wind turbine, sand, and clay characters were anthropomorphized, and their traits were similar to those of the human characters (arrogance, stubbornness, selfishness, and ignorance); these characters can be considered metaphors for humans. One of the creators of the selfish and fame-seeking bacteria character said, *"the analogy with the bacteria community stimulates multiple level-reading"*.

Most companions in the stories were animals, and we also saw a tree, water, and a genie; see Figure 1. They all displayed solidarity for the animal heroes or awareness and enlightenment, which they communicated to the human heroes.

In the story-focused workshops, nonhuman, human, and human metaphor heroes were picked about equally. Noticeably, the human metaphor characters were all developed by participants of the second workshop, i.e., professional designers and senior students at a design research conference and conveyed more conceptual stories. This can be related to the high level of abstract thinking of the participants. In the rest of the paper, we will use the term human character to encompass human and human metaphors.

In the persona-focused workshops, mostly nonhuman characters were picked. This can be attributed to the fact that participants had more time to think about their choice for a Planetary character and explore nonhuman options because the persona exercise was longer, more individual, and more immersive.

3.2. Story Themes and Endings

Most of the stories make the theme of *human/nature antagonism* explicit, expressed through nature destruction or animal killing by humans or man-made objects (*"those giants"*; *"they murdered"*) and through the voice of animals, trees, plants, or natural elements, heroes and secondary characters; see Table 2. As this theme is associated with nonhuman heroes, it is present in all stories from the persona-focused workshops. The stories that stay away from this antagonism all express the theme of *human individualism*, i.e., humans displaying individualistic behavior and ignorance. This theme is most associated with human heroes, which is why we see it more in the story-focused workshops.

Table 2. Overview of themes and sub-themes in stories.

Theme	Number of Stories Mentioning the Theme			Sub-Themes
	in All Workshops	in Story-Focused Workshops	in Persona-Focused Workshops	
Human/nature antagonism	24	69%	100%	• Destruction of forest habitat and wildlife killing by humans or man-made object • Plastic pollution and sea-life destruction by humans • Soil, air and water poisoning by humans • Humans dominating animals or nature
Human individualism	11	54%	33%	• Humans not listening • Humans not collaborating • Humans being lazy • Humans pursing individualistic goals (food, money, fame, growth) • Humans turning against each other
Union is strength	10	54%	20%	• Animals teaming up with animals or trees • Humans teaming up with humans • Humans teaming up with animals or natural elements
Learning from nature	10	46%	20%	• Animal, trees or natural elements communicating with humans to show them the reality of the environment crisis, their responsibility in it, and/or how they can contribute to solving the issue • Humans confronted to the beauty of nature change their perspective and behavior
Humans taking action to solve the issue	6	38%	7%	• Humans preach for action (stop pollution, stop destruction, initiate vegan movement . . .) • Humans concretely act to solve problem (use eco-friendly material, replant trees . . .)

All the stories position these negative themes as struggles to overcome. Positive themes are used to provide solutions, namely, *union is strength*, i.e., characters teaming up for a successful outcome; *learning from nature*, i.e., listening to animals or nature creates knowledge and awareness for humans; and *humans taking action to solve the issue*, i.e., pro-active attempts to stop or minimize threats to animals or nature. The theme of *union is strength* is expressed mostly through teaming up of same-type characters (between humans or between nonhumans), and occasionally between humans and nonhumans. Constructive human-nonhuman interaction is rather expressed through the theme of *learning from nature*, where companions, whether animals, vegetal, or spiritual, enlighten humans. The theme of *humans taking action to solve the issue* is carried by human characters. These positive themes are present in similar proportions in the story-focused workshops. In the persona-focused workshops, the positive themes were less present as the stories were less elaborated and often stopped at the tension part of the story arc.

A total of 20 out of 28 stories conclude with a positive or mitigated but hopeful message: animals' final oath to act to save their world, a call to awakening or action, human transformations to more eco-awareness, humans supporting endangered animals or forests.

Out of the 8 stories with a negative ending, half concluded with the death or pessimistic outlook for the main character or its family. One of the writers of *Shelly*, the dramatic tale of a little turtle fighting fishermen, commented: *"During the writing we all noticed we really wanted a happy ending but we realized that that might not leave the right message"*. Several of these negative-ended stories leave doubts on possibilities to limit or repair environmental damages through ambiguous final messages. For example, the wind turbine tragedy (see the story of *Daisy* in Appendix A) highlights that sustainable solutions can be double-sided.

3.3. Creation of Empathy for the Planet

Many stories featuring nonhuman protagonists include vivid descriptions of forest, land, or sea-world destruction and create dramatic moments through descriptions of the intense emotions of the characters (read *Finding Plastic* in Appendix A as an example). Many of these stories include the death or wounding of a companion or parent. Participants explained that they try to convey empathy by showing the consequences of destroying nature and killing animals through the eyes of the nonhuman protagonists, by showing their pain and sadness when they lose their home or family, and by showing that humans are responsible. They intentionally positioned them as victims and humans as enemies to elicit shame and doubt:

> *"In our story we tried to communicate empathy for the sea life by giving fishermen the bad guy role and showing how abruptly they can destroy sea life animals' lives. Leaving the animals in pain."*

> *"We tried to make the character Nemo, which everyone loves, be very pathetic. His house is destroyed, his home is destroyed and all his friends are gone. And with the context that the world and men have done all this, you start to think about Nemo and really realize what we do. You feel guilty for what you did to him, even if it's just a fictional story."*

A student criticized this dramatic approach, stating: *"As far as I'm concerned, [the facts] are so horrific that they don't need to be surrounded by a pathetic story to have impact."*

The stories that used humans or human metaphors as heroes have different mechanisms to create empathy. The participants said they created familiarity and emotional connection by showing the flaws of their characters and describing their worldview. Several designers reported that emotions were intentionally contrasted, *"sort of bittersweet"*, to highlight conflicting values. These human-centered stories focus on raising awareness and a positive lens for the possibilities for humans to act and mitigate the environmental crisis. For example, in several stories like *The Cunning Monkey Enlightening the Naive Girl* (see Appendix A), story creators showed that mindset and attitude change is possible. Participants explained:

"The story should create a feeling of familiarity, and causes people to think as the main character. It will let people ask questions and let them doubt about their own purchasing habits."

"[The story] generates empathy for the innovative woodworker and his ethics. You feel like that is the way forward and that the cutting of new trees is not always necessary."

In most of these stories, besides empathy for the human characters, participants communicated empathy for the Planet through secondary animal or natural characters who convey the message that nature should be treated with kindness.

In several stories humor was used to de-dramatize the negative emotions evoked by the suffering of animals, to create an ambiguous relationship with the human characters, or to show with irony the human failure to connect and care for the environment and the absurdity of human ways of living. Humor contributed to making the process more engaging: *"I had a lot of fun, using anthropomorphism and telling a story with humor, despite the tough reality for actual species. It made me want to write short stories and explore other personas to empathize with other species and elements and perhaps get others to empathize."*

3.4. Emotions Evoked by Stories

The emotions associated with the stories were mostly negative emotions, in particular sadness, fear, worry, anger, disappointment, irritation, regret, see Figure 2. These negative emotions are most found with stories with nonhumans main characters. The participants who created stories with human or human metaphors report fewer and more positive emotions, especially hope and compassion.

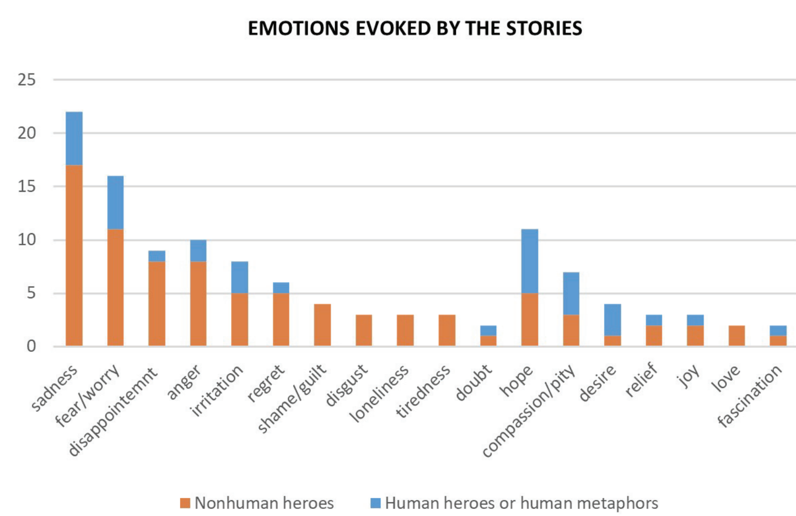

Figure 2. Overview of emotions reported by the participants when writing the stories, for nonhuman heroes and human (or human metaphor) heroes. The y axis indicates the number of respondents mentioning the emotion.

The participants reported their own emotions, but we noticed that they often also reported the emotions of the story characters that they experienced as well. Several participants described as a new experience the process of feeling for a nonhuman character. *"The story made me feel pity for the wind turbine, as if it was a person not knowing much about how the world works getting hit by reality hard. [. . .] We felt really bad for Daisy [the wind turbine]. It is interesting to feel so bad for a fictional character. It was a new experience for me. I get often* *irritated when the word empathy is used—what does it really mean? [. . .] This was empathy beyond the buzzword."*

3.5. Experience of the Story Co-Creation Process

Participants reported that the process, through collaboration, exchange of ideas and perspectives, playfulness and creativity favor new or deeper reflection and is a motor for team discussion about the environment, see Table 3 for detailed feedback. The connection to the characters, taking their perspective and experiencing empathy was also an important aspect of the process and was qualified several times as eye-opening. The collaborative aspects were most reported in the story-focused workshops, which can be explained by the longer time assigned to the participatory exercise. Comments about the creative benefits and the connection with the characters came back more in the persona-focused workshops. For the aspect of connection, this is due to the emphasis on the persona exercise. For the aspect of creativity, we can stipulate that this type of creative workshops is not common practice for non-design stakeholders and is particularly enjoyable—a result found in our previous research where we applied story co-creation with scientists [49].

A participant's quote summarized all these benefits and enablers: *"Story co-creation was a fun exercise, especially merging the inputs of three people into one story. I felt that the collective input made the story even more rich and something different from what I would have done alone. [. . .] Along with creativity, I think this exercise was also critical to developing empathy with our surroundings and storytelling workshop was a very good tool in achieving that."*

Participants in general appreciated the templates that facilitated the creative process, yet several had difficulties developing their personas or stories, getting 'in the creative flow', or needed more time, especially in the shorter (2 h) workshops.

3.6. Short-Term Change in Perspective and Behavioral Intention after the Workshop

About half (23 over 51) respondents, mostly in the story-focused workshops, indicated the intention to use more storytelling elements in their work after the workshop, see Table 4. The intention to use storytelling in their practice was higher for the designers and students than for the business stakeholders, probably because storytelling is a skill familiar to designers.

Sixteen respondents reported an increased awareness of environmental issues, and seventeen indicated an intention to consume more responsibly or to create more sustainable impact in their work. Eleven participants declared that the workshop did not change or impact them, most of them because they were already active in the field of sustainability. Noticeably no professional designers not senior students reported environmental awareness or intention of change, which we can attribute to their more mature ecological identity.

We stress that these results reflect the mindset of the participants shortly after the workshop and that we do not have data on their long-term mindset or behavior.

Table 3. Overview of benefits, enablers and difficulties of the process reported by the participants and illustrative quotes.

Experience during Persona and Story Creation	Summary of Experience Element	Number of Respondents Mentioning the Element		Illustrative Quotes
		in Story-Focused Workshops	in Persona-Focused Workshops	
Collaboration and exchange	34 respondents expressed that the story co-creation stimulates collaboration, exchange of ideas and perspectives. The process challenges them to listen to and embrace suggestions, to consider different opinions and perspectives (including those from people who do not share their values), to look at problems differently. As a result, the process helps to go more in depth with ideas and to improve their reflection. Several respondents mentioned that it is a good team building exercise as it connects people and a good medium to facilitate a discussion about the environment and sustainability.	80%	48%	*"It was a great way to connect our ideas and dive deeper in the problem."* *"My team was very diverse and being able to execute a task with people who thought so differently was fascinating, exciting and taught me to compromise on expectations."* *"The story is a really strong method to get organizations reflect on their current behavior, and at least start the conversation. Love the way storytelling creates the opportunity to discuss change and innovation in the form of metaphors. This way it may at first not be as confronting and stimulate co-creation from different perspectives."* *"I really relate to the story because I've been to Malaysia and expected only beautiful things but saw a lot of shocking things, like pollution, dead coral reefs and big palm tree plantations. I've seen the jungle before and there I saw it getting destroyed right before my eyes. [...] I realized that the people that don't share the same mindset as me (wanting to contribute to a more sustainable world) don't have it because they haven't seen it up close like I did."*
Connection to characters	23 respondents said that the persona creation exercise made them see the world from the character's perspective and feel closer to them. This was for many a new experience. Being immersed in the creative process during the workshop, relating to personal experiences and memories, and assigning human attributes to nonhuman personas helped them creating this connection. Many in the persona-focused workshops mentioned that the detailed persona templates pushed them to go in depth, inspired them and triggered their imagination.	23%	76%	*"Personally, it was a bit of an eye opener, we don't frequently think of being empathetic with our Planet (really putting ourselves in its shoes)."* *"I like the idea that we were asked to get into the head of the persona and think like we are them. I loved this experience as it was eye-opening."* *"To me the creation of the persona was really a super valuable experience and the most interesting part of the workshop. Thinking about what the persona sees and feels really helps to enable an ecosystem mindset, thinking about all the connections the plant, animal or else has in this world and how all actions have impact. Very emotional exercise."* *"I liked realizing how it changes the way one thinks about parts of nature, which is in a more personalized way. This increases the felt proximity to the things that surround us. They start playing sort of a role in our life more."* *"I used my memories of spending time in the ocean to build a story that could reflect the ocean's feelings."*
Creativity and playfulness	18 respondents associated the entertaining aspect (the word 'fun' came back in most of these answers) to creativity in the process. They see this combination as a motor for new ideas: they enjoyed listening and building upon others' ideas and being surprised by their creativity.	23%	71%	*"It was fun, because we came up with a fantasy story which i did not expect. Therefore this exercise helped me thinking outside the box."* *"I usually write by myself, I don't have 2 other brains with me. It's incredible to have 2 [extra] creative brain."* *"Really enjoyed coming up with ideas and building on the ideas of teammates. It made for coherent pieces that could surprise each other."*

Table 3. *Cont.*

Experience during Persona and Story Creation	Summary of Experience Element	Number of Respondents Mentioning the Element		Illustrative Quotes
		in Story-Focused Workshops	in Persona-Focused Workshops	
Difficulties in the process	11 respondents expressed that the creative process (setting the scene, creating the characters and the plot) was difficult sometimes. Several participants in the persona-focused workshops felt that the story creation exercise was rushed.	13%	33%	*"I found it challenging to let the creative juices flow at first, but working with my colleagues definitely helped."* *"Writing the [story] for some reason felt like cutting the story too short and that we lost the emotional momentum which was so powerful."*

Table 4. Overview of the reported changes by participants and illustrative quotes.

Expressed Change or Intention of Change after Process	Summary of Change or Intention of Change	Number of Respondents Mentioning the Change		Illustrative Quotes
		in Story-Focused Workshops	in Persona-Focused Workshops	
Intention to use storytelling and personas in work practice	23 respondents expressed the intention to use elements of storytelling and personas in their work, mostly to talk about their projects, to show different perspectives and the bigger picture, and to trigger an emotional response.	60%	24%	*"It is a good teaching tool: it is good to learn how to communicate what you do but also to understand why you are building what you are building (like a chair). A better story and a better chair will come out."* *"A good story takes us a long way in our sustainability efforts. When we're able to engage stakeholder from an empathetic approach to our Environment we'll be able to get their attention and make them feel the urge to act."* *"After the workshop I have thought increasingly of characterization and personification of the abstract and inanimate as a powerful storytelling tool."* *"I do think storytelling can have an impact even if you may not be aware of it at first. I liked learning how a story can draw empathy/attention and hearing different opinion. I want to address in my design brief that there isn't one side to environmental change. And talk more about how it can change by communicating with the people and business."*
Increased awareness of environmental issues and consequences of actions	16 respondents declared after the process made them more aware of the size of the issue and of the consequences of their actions on wildlife and nature.	20%	48%	*"The story did motivate me more to be more aware of what is happening around me and try to understand the consequences of my actions. This is due to the fact that via the story, you can realize that your actions can have severe consequences even if those consequences are for someone [. . .] who cannot talk in real life."* *"It made me think about on-land problems and sea problems and it made me realize that environmental issues are huge and way bigger than anyone can even imagine, but we still have to act."* *"You should really think twice before you do something, so you don't hurt anyone else in the process."*

Table 4. *Cont.*

Expressed Change or Intention of Change after Process	Summary of Change or Intention of Change	Number of Respondents Mentioning the Change		Illustrative Quotes
		in Story-Focused Workshops	in Persona-Focused Workshops	
Intention to make changes in work practice to create more sustainable impact	11 respondents want to have more sustainable focus and/or impact, for example by including systemic considerations, initiating dialogue or reflecting on the ethics of innovation in their projects and business transactions.	20%	24%	*"I want to see people, profit and planet as equals and involve them all in my product design."* *"I will prompt the question 'what would the planet think about that?' in future business cases."* *"Thinking and feeling from the planets perspective as a tool in decision making is a huge AHA moment!"*
Intention to consume more responsibly	6 respondents expressed their intention to stop buying unnecessary items, to live with less, to be more informed of the origin of products, to use less plastic or more recycled products.	17%	5%	*"The story made me become aware of what I need and what I don't need. So that I can stop buying unnecessary purchases."*
No change	11 respondents said they would not change anything after the process, mostly because they were already motivated to work on sustainability before.	20%	19%	*"I already had the motivations to do something better for the environment."* *"Can't say that it changed anything. But I consider myself as someone who is already very aware about my values/behavior/prejudice—because of my work with design for sustainable behavior, so I don't think I am the typical audience for such a workshop."*
No answer	8 respondents do not know or did not answer the question.	20%	10%	

4. Discussion

4.1. Mechanisms for Creating and Experiencing Empathy for the Planet through Participatory Ecological Storytelling

The stories created by the participants can be grouped into two categories. In the first group, the protagonists are animals, trees, or natural elements facing human antagonists who destroy their habitat and/or kill their companions. These stories are associated with sadness, fear, disappointment, and anger. Participants create empathy by anthropomorphizing the nonhuman characters, describing their intense emotions, and showing their pain. They intentionally position nature as the victim of human enemies to elicit guilt and shame. The second type of story relates the transformation journeys of human heroes towards more eco-friendliness. These stories are less emotional and more positive. Participants create familiarity and emotional connection by showing the flaws of their characters and describing their worldview.

We can distinguish here two strategies that participants use to create empathy for the Planet: directly by trying to take the perspective of nonhuman characters, or indirectly through human or metaphorical characters who experience or discover empathy for the Planet in the story. The story creators do not experience exactly the feelings or thoughts of the characters—this is especially impossible for nonhuman characters—but they attempt to understand them as individuals, which is the basis for empathy creation [9]. At the same time, story creators project their own values, emotions, and thoughts, onto the characters and identify with them. For both type of stories, participants reported that experiencing empathy by taking the perspective of story characters was a new, deep, and eye-opening experience. Relating to the concept of "narrative empathy", where an audience uses imagination to adopt a character perspective [70] but that is generally experienced while being the receiver of a story, here participants who are story creators practice "active narrative empathy".

The choice of the character and the associated empathy creation strategy reflects the motivations and understanding of climate change of the participants. In the first set of stories, the heroes are the "good guys", in the second they are the "bad guys", and this positioning reflects, respectively, a sense of powerlessness or responsibility of the story creators with respect to environmental challenges. Nikoleris explains that in fictional ecological narratives, identification with the characters—heroes, victims or villains—helps people create meaning around changes that are difficult to grasp [80]. In fictional story making such as here, where participants do not have to explicitly reveal their personal emotions or experiences, the distanciation from reality may create a safe space for expression. In the first group of stories, the expression of negative emotions and possible identification with victimized heroes while highlighting feelings of shame and guilt through the description of destructive human activities may be a way to process these emotions and the anxiety linked to uncertain futures. The second group of stories expresses through human characters a recognition of one's own flaws such as selfishness, individualism and ignorance, and indicates self-reflection and awareness of how one's lifestyle contribute to environmental problems and the need for individual change.

The stories are written from the perspective of the sympathetic follower of the protagonist or as critical examiner of the protagonist's view, following known archetypes in climate fiction [80]. The two types of stories can be related with two of the frames most commonly associated with climate change: the frame of 'conflict' (fighting a "war" against climate change) and of 'morality' (becoming aware of responsibility and stewardship) [14,123]. It is known that metaphors, a mental projection of a complex or vague concept onto an understandable representation, are activated and communicated by language and help expressing frames [124]: here the stories are the metaphors expressing the frames. A participant mentioned that participatory storytelling is an engaging, non-confrontational way to open dialogues about environmental challenges because it uses metaphors.

If we compare the stories created in the workshops to common story archetypes [125], the first group generally matches the plot of *overcoming the monster* (a story where the hero is attacked by threatening antagonists and must fight—here nonhumans confronted to humans destructing their habitat and killing their companions); the second matches the plot of *rebirth* (the hero undergoes a dramatic event that makes them reconsider their thinking or behavior and change—here humans transforming to reconnect to nature). Because these story archetypes are extensively used in the media industry, and because they reflect the common frame of 'conflict' and 'morality', it is not surprising to see them dominating the story creation here.

A major role of these stories could be to counteract the effects of doom and discouragement. The climate crisis conveys a large range of negative feelings and overwhelm, which can be paralyzing, an effect reinforced by the framing of climate change as threatening and distant. Eco-anxiety and a gloom and doom vision may lead people to emotionally and cognitively shut down and to denial, rejection, and avoidance of the climate topic [14,126]. Making the topic closer and personal and associating it with positive emotions, especially hope and empathy, is an important path to inspire and motivate engagement [127,128]. Here the stories are personal and express forward-looking endings: the first group of stories almost always end with a call or an oath by nonhuman characters to act on a collective level, which may reflect a desire of the story creators not to stand still and to see transformation on a societal level; the second group reveals a desire for progress through personal transformation or enlightenment.

Furthermore, emotional fluctuations in stories, i.e., experiencing emotional highs and lows from protagonists or liked characters, have been shown to promote greater identification, continued engagement with the narrative world, and higher persuasive potential of a story—in particular, after being exposed to negative content, the positive emotions triggered by positive content are amplified [127,129]. Here, emotions associated with negative themes of human/nonhuman antagonism, human individualism, ignorance, and destructive actions are balanced out by hopeful endings and positive themes of interspecies collaboration and learning from nature.

The main difference in the strategies to create empathy between the three groups of participants (design students, professional designers, and business stakeholders) was related to these emotion fluctuations and the associated themes. In the persona-focused workshops, participants had less time to elaborate on the positive themes, while the story-focused workshops resulted in stories with richer and more contrasted emotion patterns. We observed that the creation of stories with sufficient richness takes time (at least 1.5 h), which should be taken into account when designing future workshops. The persona- or story-focus of the workshops also resulted in a noticeable difference in the experience of the process: extensive and immersive persona creation stimulated to a larger extent creation of nonhuman characters and empathetic connection; long story co-creation exercises were stronger in stirring creative idea sharing, team building, and understanding of the perspective of other participants. An optimal process might hence take the form of a full-day workshop combining extensive Planetary persona and story creation.

4.2. Positioning of the Findings on Participatory Ecological Storytelling in Existing Knowledge

In the introduction, we reviewed existing work on participatory ecological storytelling using essentially human characters, which is a powerful tool for self-investigation and self-expression, collective sense-making, and individual and collective transformation towards pro-environmental engagement. We see a reflection of these findings in the stories of this study that used human heroes, see Figure 3. However, the perspective of the Planet is often missing in these efforts. We also reviewed how non-participatory literature and communication using nonhuman characters can assign agency and moral kinship to the nonhuman and create empathy for the Planet. In this study, we combine the benefits of the participatory process and the use of Planetary characters, building on the work of Donly, Nanson and Gersie et al. [3,50,58] that investigates the connection between individuals, groups, and nature, via participatory storytelling involving nonhuman characters. We also respond to the need for a creative, collaborative, and nature-inclusive tool applicable in sustainable design processes [8].

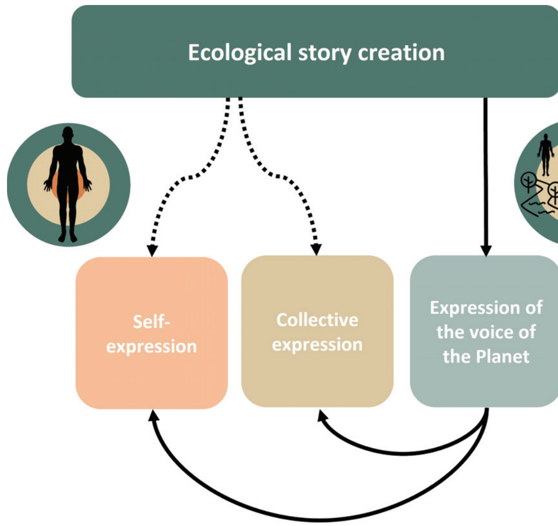

Figure 3. Graphical representation of the mechanism of participatory ecological storytelling. The doted arrows represent the effect of story making with human characters, and the bold arrows with Planetary characters.

We observe that through the expression of the voice of nonhuman characters, not only empathy for the Planet is built, but also self-expression and collective dynamics are activated; see Figure 3. Stories are the 'boundary object' between the expression of the voice of individual story creators, their group and the Planet. Important elements are stimulated by storytelling and relevant for all expression pathways, such as emotional literacy that favors introspection and empathy for other humans and nonhumans, or connectedness that is essential in building social narratives and relating to the nonhuman. This step through Planetary characters is essential to appraise sustainability efforts through a Planetary lens instead of an anthropocentric lens.

The two approaches can be complementary, for example, when Planetary characters are used for mindset shift and human characters for the definition of personal action. They can also overlap in the context of social sustainability when Planetary characters are based on humans that belong to different socio-cultural groups.

4.3. Positioning of Empathy for the Planet in Post-Anthropocentric Thinking and a Preliminary Definition

The created stories position the nonhuman in constructions that are typical of Western thinking, namely nature and animals as vulnerable victims of human actions (for the first set of stories) or as the enlightened source of transcending experiences (for the second set of stories). While we did not encourage these constructions in the workshop, they emerged, a testimony of our engraved narratives. This type of narrative has been said to support a positioning of nature as distinct, and sometimes inferior, to the human realm [3,96]. Story archetypes that highlight the human-nonhuman antagonism, such as *overcoming the monster* have been criticized as feeding the psychological distance between the human and the nonhuman [3]. However, we observe that the process manages to go beyond this dualistic construction. The nonhuman world is given knowledge and agency in both sets of stories, through heroes, companions or teachers, which is a driver for shifting to a post-anthropocentric mindset [3,34]. The active projection of the story creators into nonhuman characters engages with nonhuman interests and a reappraisal of nonhuman agency and human-nonhuman interactions [35]. Anthropomorphizing animals and trees invites a degree of empathy: as Nanson stresses, *"To enter the viewpoint not merely of another person but of another species, with its own 'umwelt', may seem an impossible feat, likely always to involve some degree of anthropomorphic projection. Contemplation of that gap of understanding creates a tension, a kind of desire, that can motivate the exercising of the imagination to reach across the gap and at the same time accepts as part of the richness of the universe the mystery of that which is beyond one's comprehension and control"* [58]. The emotional projection into nonhuman characters is an attempt to bridge this gap. The self-reflection through human characters enlightened by the nonhuman world is a contemplation of this gap; contemplating the gap with the Planetary realm is already building a relationship with it.

Even if the stories are centered around individual characters' struggles and motivations, sometimes divergent, the blending of the human and nonhuman through the stories makes a common goal emerge—the well-being of the Planetary ecosystem. This is similar to the positioning of eco-narratives by Donly, which *"explicitly foregrounds ecosystemic goals over individual ones"* [3]. The positive exchange dynamics with the other participants also contribute to building this shared goal in the human group.

Looking at the cognitive, emotional, and compassionate elements of empathy, we see that empathy for the Planet stimulated through participatory ecological storytelling has a significant affective component (projecting emotions onto and feeling emotions for the characters) and a compassionate component (creating interest for the characters and stimulating action). These have a role to play in driving design decisions and motivating action. Participants also bring into the process cognitive empathy for the other story creators, stimulated by the open perspective sharing: cognitive empathy within a team can act as a cognitive based "social sensitivity" [130]. However, the cognitive aspect of empathy for the Planet is limited by the little knowledge that the story creators had about the characters natural history, inner world, and environment. There are arguments that environmental knowledge is more decisive that empathy in determining pro-environmental attitudes and that environmental decisions should be guided by reason and science [131]. Others promote emotions and compassion as partners of reason in caring for the environment and in addressing the related ethical questions [26–28]; they stress the urgency of raising people's empathic response to environmental problems [50]. In our view, empathy creation, as well as assigning agency to the nonhuman and acknowledging differences, is a motivator to seek environmental knowledge by making designers and stakeholders compassionate and curious. However, we recognize that more knowledge about the subjects of the story might be beneficial in building cognitive empathy and promoting a fairer inclusion of the Planetary characters.

To summarize, empathy for the planet stimulated through participatory ecological storytelling is a relationship with Planetary entities based on imagination of their emotions inspired by our own emotions, and of their reactions inspired by our desire for action, stirred by a shared compassionate ambition to care for the Planetary ecosystem. Empathy for the Planet is close to the concept of 'entangled empathy' explored by Gruen for animals, i.e., a caring perception focused on shared feelings and driving an improvement of the relationship with the other [132]. Stories create a space for sharing of the human and nonhuman emotions and hopes and for blurring the boundaries between entities in line with posthumanist thinking.

4.4. Limitations of This Study and Suggestions for Method Improvement

The designers who joined the ecological storytelling workshop were all already interested in the topic of sustainability and joined voluntarily. Hence, the sample group was favorably disposed. People interested in and acting on solving environmental issues generally display stronger altruistic traits [24], which may have facilitated the application of the method and the creation of empathy for the Planet. Applying the method to less engaged participants might require a modified approach and give different results. Furthermore, in the persona-focused workshops, we only gathered responses from half the participants, meaning that we may miss out on different experiences and opinions.

We have not looked at the consequences of the process on participants' personal or professional decisions and actions. It is known that storytelling has a short-term impact on beliefs, concerns, and attitudes about climate change but a limited impact on efficacy and action [31,133]. To improve the desire and sense of ability to take action, we should consider strategies that develop participants' understanding of tangible and accessible ways to act, of the specific outcome of individual actions, and of the link between individual and collective action [31]. This could be done, for example, through follow-up workshops where participants reflect on their personal stories of change and commitments, such as in the transformative story making method developed by IDeaLs [134].

Finally, the creation of the characters and their world was mostly subjected to imagination. Even though the act of imagining how a different entity might experience the world is key in opening to other perspectives [135], there is a risk with our method to build 'false empathy'. To properly take the affective perspective of another and build cognitive empathy, it may be beneficial to have knowledge about the subjects that inspire the characters [2,63] and to use imagery, names of individual species and land features to create a more immersive story world [58]. Other options to stimulate knowledge or connection to the subject and the world of the story could be to take the bodily perspective of the other e.g., through role playing [63] or virtual reality experiences, or to build sensory awareness for the natural world through holding the workshop outdoor and using present natural entities to build the stories [58]. The potential of participatory ecological storytelling where the participants are more knowledgeable about the needs and context of their character subject should be investigated.

4.5. Applications of Participatory Ecological Storytelling and Empaty for the Planet in Sustainable Design Practice

Systemic design competences: Developing empathy for Planetary stakeholders is a first step towards understanding and integrating their needs when designing for sustainable solutions with a systemic approach. Additionally, a mindset shift where one appraises the value of relationships and is comfortable with uncertainty is necessary to approaching complex system design [136] and is stimulated by the method. Participatory storytelling stimulates humbleness, openness to the unknown, overcoming prejudices and mental barriers though the play-like creative process and discovery of the other (the other participants or the characters of the story). All these factors help reassigning one's position in the ecosystem and accepting forces that are out of our control and knowledge. Participatory ecological storytelling can be a powerful tool to create systemic awareness, that can be used for example at the beginning of a systems analysis process to create the right mindset or as an introductory tool to systems thinking.

Community building: The creative, collaborative and team-building benefits of the story co-creation process expressed by most participants are in line with the previous work on participatory storytelling [3,49,83,94]. The reported link between engagement, fun and creativity—the " creative magic" [51]—is important to elicit a positive dynamic in discussions around environmental challenges and sustainability. Groups and communities play an important role in promoting actions that help to mitigate environmental problems [137,138], and it has been shown that individual pro-environmental engagement becomes stronger when the individuals belong to a group endorsing pro-environmental values [139]. Participatory storytelling can become a powerful tool for organizations to build communities sharing co-constructed pro-environmental values that drives the sustainability transformation.

Communication competences: Many designers and students expressed the intention to use more storytelling elements in their work to create awareness for different (including nonhuman) perspectives, create an emotional connection and foster a mindshift. Storytelling skills will be key in designing engaging and effective environmental communication to promote action, material and social change within organizations and for general audiences [29,30,105]. By learning to make stories, designers gain the capacity to deal with complex information, to articulate difficult emotions, to manage feelings of overwhelm and helplessness, and to elicit goal-oriented action and solidarity—for themselves or for the audience of the stories [50,110,140,141]. Participatory ecological storytelling is a hands-on learning tool to start developing such skills.

Design research competences: Storytelling can be an interesting tool to understand how people interpret environmental challenges and construct their perspective. Storytelling is used as an inquiry tool in design research to provide access to rich and nuanced information about users' emotions and frames that may not be available via other means of research [110,142]. These insights can be used to design positive experiences around sustainable solutions, effective behavior change and communication strategies. It is good to keep in mind that stories inherently carry ambiguity and their analysis should be treated with caution [117], and that the stories created by the participants are not per se the best way to approach people when communicating about environmental challenges. Rather, these stories can be the basis for understanding how to design narratives and solutions aligned with a certain target group values and worldviews.

Behavior change: This study was not aimed at looking at behavior change, however the results suggest that participatory ecological storytelling could be a tool to stimulate pro-environmental awareness and action through compassionate empathy, processing of negative emotions and expression of hope. Participants, by trying to understand Planetary stakeholders, also develop more understanding about themselves and may build emotional literacy. This can lead to a value shift relevant for sustainable design as indicated by the intention of change of some participants in this study. Further studies are needed to evaluate if the method can durably influence the engagement and mindset of the participants.

In this study we focus on the impact of storytelling for design, yet we also see benefits for a larger set of stakeholders such as in business and marketing. The engagement power of storytelling is universal, and this method is a good starting point to make difficult environmental topics more approachable and engaging for varied audiences—e.g., general public, innovation, business, political stakeholders, with different interest levels in sustainability. It would be interesting to study and optimize the method for different generations, professional and socio-cultural target groups.

5. Conclusions

Participatory ecological storytelling is a promising approach to create empathy for the Planet through imagination of the perspectives, emotions, and experiences of Planetary characters and through creating and sharing between story makers. Empathy for the planet initiates new relationships and reunites the human and the nonhuman through a common goal—that is to serve the well-being of the Planetary ecosystem, a fundamental building stone in creating a healthy a sustaining future.

The method is highly applicable in a design context across several competences, and beyond—for example in a business or marketing context. It provides a bridge to inclusive design approaches and to new ethics to designing with the human and nonhuman in mind. On one hand, the methodology shifts participants' mindsets towards appreciation of the nonhuman and may stimulate inclusion of the needs of the whole ecosystem in sustainable design processes. On the other hand, it makes participants' emotions and desire for transformation and action regarding environmental challenges explicit and processable.

Participatory ecological storytelling and the notion of empathy for the Planet opens an emotional and intuitive way to approach sustainable design, complementary to the factual and material approaches such as circular design and circular business model creation. It enriches design competences like systemic design, communication design, design research, behavioral design and in community building. Last, but not least, it could be a strong contributor to organizations' sustainable transformation, whether an organization needs to take its first sustainable steps or to accelerate ongoing progress.

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Appendix A. A Selection of Illustrative Personas and Stories

Finding Plastic.

Nemo has just been rescued from the dental business by his father. Nemo no longer wants to do nothing and wants to go on an adventure. His father goes with him, he now understands that the ocean is big and still so much to explore. After a few years, Nemo and his father return home. They wanted to see their friends again and see how Dory was doing.

When they arrive home, nothing of their hometown is left. All the plants are gone and the sand is black. Oil tanks lie on the ground and oil droplets float above them. There is nothing left of their house. The plant is completely dead. All their friends are gone. Nemo decides to go to the residence of his old school friends to see if they are still there. He sees a fish skeleton. Suddenly a fish comes towards him. "Nemo, where have you been all this time?" It is the ray, the teacher at his school. He has a plastic band around his neck, Nemo doesn't know what it is exactly. "Our house is broken. The people. They did this." The ray falls to the ground and does not get up again. "Daddy, what happened while we were gone?" "I don't know, son." 'What is that sound?' says Nemo. Nemo and his father swim up and see numerous oil ships on the water. They see a man throwing an old oil tank into the water. And another one. Only waste floats on the water. "Daddy, it's so dirty. I can't swim anymore." The boat next to Nemo and his father sails away; because of the current a huge wave comes at them, full of garbage and plastic. Nemo's father is dragged along. "Daddy, no!" Nemo goes after his father and tries to save him. It is completely wrapped in a plastic bag. The same plastic bag Nemo was in when he was going to be given to Darla. "I can't breathe." says the father. "Nemo, save yourself!"

Nemo's father is dragged away and Nemo is alone. "What the people have done cannot be undone. See what they're doing to the underwater world. Look who they kill with their actions. No. I will stop the people and rid the oceans of this plastic soup. A fish should swim in the sea, not drown in men's waste."

The Cunning Monkey Enlightening the Naive Girl.

There was once a girl living in her own bubble and quite spoiled by her own family. She was very influenced by social media and had the ambition to explore the world to take nice pictures for her social media account. For her next trip she went to Malaysia.

She arrived at Kuala Lumpur and planned a trip through the center of the city with a canoe. Halfway through the boat trip, a tropical rain started. She started a whole mantra about how things weren't to her expectations. However, while she was complaining about being all wet, cold, and other smaller problems, a monkey jumped out of a tree on the boat. The monkey didn't want to stay in the tree due to all the rain and the possibility of being electrocuted by the storm. Thus, he jumped in the boat. The girl got shocked when seeing the monkey and the monkey started talking to her. He said to stop complaining about the weather and look around for a second. So she did. She started to see all the plastic that was thrown into the river and how little birds or other small creatures were stuck in plastics and garbage. She realized how there were far more important things going on than her small problems. She realized how good her conditions were relative to what was happening in Malaysia.

This trip to Malaysia really opened her eyes and back into her own bubble she became more aware what needed to change. Instead of looking at social influencers she started to look at greener organizations. She wanted to change the conditions all over the world but needed to start with herself first. The monkey started to trust people more when he saw that the spoiled girl could change as well and started to approach more tourists to see what the state of the planet actually was.

Daisy the Wind Turbine.

I am Daisy. I used to be a God. I could touch the clouds and see far and wide and look down on the ants on the ground. I want to tell you about how I was supposed to save the world. I was here to help. I did good.

I was standing around when I was visited by Windy; Windy is my friend and tells me stories from all the places they visit. I love when Windy visits and tells me about the lives of birds and ants! That day, however, she told me about how others of my kind are doing more harm than good. How can that be? We're here to do good! I promised Windy that I would never do something like that.

The next few times Windy visited things were different between us. I felt like she was judging me. At first, I could not believe how she was acting. But then my world turned upside down when I killed a bird. I killed it because I am metal and wires. Because I was stuck. I didn't want to kill the bird, I didn't want the forest to be destroyed, so that I could be here. But Windy didn't know . . . listen . . . care . . .

Windy left that day, and never came back. When she's not here I cannot move.

The ants dismantled me. Took away my wings and took me down from the clouds. Now I am in boxes, separated in parts. I still wait for Windy to visit me one last time.

The Great White Ocean.

What you can see:

(1) Their physical appearance: their shape/body, the way they move/walk, the way they dress/transform.

I am big, wonky, out of shape. Whenever I move, everyone notices it. It is impossible for me to be invisible which, on the other hand, gives me power and visibility.

(2) The sounds they make or their way of talking. Their silences.

I am always in motion, even when I am asleep or apparently quiet. And I create a soothing sound which can be soothing or scary depending on how powerfully I move.

What's happening inside:

(3) Their character: the way they think and feel.

I get frustrated when it is too windy. I feel like a connector of many parts. This comes with both an opportunity and responsibility. I feel beautiful, but old and run down. I used to be in a better shape but got a bit carried away and am struggling to get back on track. Sometimes I wish I had an extreme makeover.

(4) Their past: an important memory, a trauma, a learning experience.

There was this one time when everyone vanished all of a sudden and I was left alone. That is when I developed attachment issues. I mean nothing when everyone is gone.

(5) What they love and dislike.

I love depth, colors, diversity and inclusion. I dislike lack of respect, bullies, and being taken advantage of.

Their world:

(6) Who/what is around: family, friends, animals, plants, natural elements, enemies . . .

Around me are seaweeds, plants, fishes, bacteria, humans, cruise ships, boats . . .

(7) How they make those around feel (good and bad).

They are pretty small when I wake up. They better not mess with me!

Their story:

Dear little humans,

I'm the Great White Ocean. I used to feel beautiful and now pollution is making me sick. I am struggling to get back into shape. I gave it my all, my best years. But I feel I am getting lonely, and I am afraid. I am nothing if I end up alone.

I have asked you help many times but now I have made a decision to join forces with the Sun and remove you, humans, from the equation of our existence.

Goodbye, The Great White Ocean.

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sustainability

Article

Sustainable Design Orientation in Furniture-Manufacturing SMEs in Zimbabwe

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Abstract: Small and Medium Enterprises (SMEs) have become the backbone of many nations as they contribute immensely to the growth of their economies. In Zimbabwe, they have filled in the gap left by the big companies after the economic crisis of the early 2000s. The impact of SMEs is small when we look at their environmental, economic, and social impact, but when grouped, it becomes a considerable contribution. Evidence from the literature shows that SMEs have a short lifespan. Therefore, sustainability in manufacturing SMEs in emerging economies and their survival strategy have been discussed. This study aimed to examine sustainability in the context of design in furniture-manufacturing SMEs in Zimbabwe. The qualitative study used a purposively selected sample of ten SMEs where the owner and/or manager and designer were the main participants. Observations were also conducted on-site in all ten cases where evidence was noted for analysis. The study reveals that SMEs in emerging economies face many challenges, such as a lack of finance, skilled human resources, and management commitment that hamper their capacity to adopt sustainable design in their practices. Sustainability adoption in these SMEs is more of adherent to the regulatory framework, especially considering the environmental aspect. The study concludes by recommending that policy makers in government should create tax rebate incentives that should be awarded to those SMEs that score highly in all three pillars of sustainability.

Keywords: sustainability; manufacturing; SMEs; design; environment; furniture

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1. Introduction

For good reason, sustainability has become a buzzword in business. With the increasing concern for the environment and the need to use resources responsibly, businesses are being pushed to look at how they can use sustainability for competitive advantage. Small and Medium Enterprises (SMEs) in emerging economies are no exception, as they operate in the same business environment as large businesses [1]. These businesses face unique challenges when it comes to sustainability in manufacturing. Like large businesses, small businesses must also participate in proffering solutions to reduce the consequences of environmental damage. Improvements in sustainability have been demonstrated to be very effective at slowing and limiting environmental damage [1,2]. Calogirou et al. [3] highlight that SMEs collectively cause environmental harm and generate more waste than all prominent organizations. This is because globally, SMEs constitute 90% of businesses and employ more than 50% of the global workforce [2]. Due to a lack of resources and limited influence over their supply chains, SMEs are less likely than more significant firms to implement transformational changes, being innovative and sustainable to remain competitive [3,4]. Studies by Cote [5] and Klewitz [6] concur that it is challenging to engage SMEs on issues to do with environmental management; hence, more work needs to be conducted in the area with SMEs [7].

Economically affluent countries tend to be home to most sustainability proponents. In contrast, business is not doing well in emerging economies as SMEs face uncertain futures [8]. SMEs in developed countries tend to pay greater attention to global elements of climate change in their economic activities, such as lowering carbon emissions as they internationalize, unlike their counterparts in emerging economies [9]. Coldwell [8] states that sustainability in emerging economies typically focuses on localized contextual elements that prioritize local political, legal, and economic factors, including profit, employment, and rapid economic growth. Starting an SME in a developed economy is more of choice to contribute to economic growth and, recently, a passion for achieving global sustainability targets. However, in developing economies such as Zimbabwe, there is more focus on seeking to earn a living, as the entrepreneurs seek to create wealth for survival [10].

Since most consumers are hesitant to pay more for environmentally friendly goods and services, it is challenging for SME managers to justify investments in social and environmental management from an economic and competitiveness point of view [11]. Environmentally friendly goods and services are good business, especially in consumer contexts where sustainability has become part of their choices for consumption. SMEs ignore their social responsibility, yet research indicates that socially conscious businesses outperform rivals in the short and long term. Additionally, the study findings indicate that SMEs' aspirations for sustainable development differ significantly from those of large businesses because of the constraints that limit them [12]. Manufacturing SMEs in emerging economies face several challenges when it comes to sustainability. Among these challenges is the need for more resources and infrastructure to support sustainable practices [6–8]. Many businesses operate in areas with limited access to renewable energy sources or recycling facilities.

Additionally, implementing sustainable practices can be prohibitive for SMEs with limited financial resources. Another challenge is the lack of awareness and education about sustainable practices. Many SMEs in emerging economies may not fully understand their manufacturing processes' impact on the environment or may be unaware of alternatives or more sustainable methods. This lack of knowledge can make it difficult for these businesses to make informed decisions about sustainability. SMEs start as an idea from an individual who dreams of the enterprise growing into a large company one day but often result in a poorly developed sustainability model [13]. The core business strategy often lacks a focus on sustainable practices to be adopted by the SME, as most of the operations are conducted informally [14].

Although the significance of SMEs has been widely discussed, the question of what an SME is still stands. Since there are differences across nations and sectors, there is no universally accepted definition of an SME [15,16]. The concept of SMEs differs from industry to industry and from one nation to another, since there are several definitions of SMEs that come from varied views among academia, organizations, and governments. The SME Act (24:12) of Zimbabwe defines an SME as a business that employs 6 to 75 employees, with an asset base of USD 250,000 to USD 2 million and an annual turnover of USD 500,000 to USD 3 million. Most scholars have looked at the sustainability of SMEs in developing economies from the dimension of their survival skills, as it is usually challenging for them to survive beyond five years in business [17,18]. Majukwa et al. [19] conclude that four factors, namely, quality, employee skills level, dedication and passion of owners, and customer satisfaction, affect the sustainability and development of SMEs in Zimbabwe. Other scholars, such as Dzingirai et al. [18], tackle the sustainability of SMEs in Zimbabwe in the context of their survival post the COVID-19 pandemic. SMEs in Zimbabwe are family run and non-family run. They contribute about 50% of the nation's GDP and 60% of its active workforce [19,20]. Masocha [1] considers sustainability from the social aspect in a typical developing economy and concludes that social sustainability and SME performance directly affect one another. Few studies attempt to explore sustainability from the lenses of a manufacturing SME in developing economies. This study tries to understand sustainability in developing economies in the context of Zimbabwe as one nation that has witnessed the importance of SMEs at a time most large companies closed their doors. The study explores sustainability in the furniture manufacturing sector, as design has played a crucial role in the growth of this SME sub-sector. The study considers sustainable design as a strategy to achieve sustainability in the furniture-manufacturing SMEs in Zimbabwe. The following research questions guided the study.

- What are your current sustainable design practices and goals?
- What are your biggest challenges in implementing sustainable design practices?
- What are some of the most innovative sustainable practices you have implemented?
- How do you engage employees in sustainability initiatives?

This research aims to add to the body of knowledge on sustainability in manufacturing SMEs in emerging economies where design is crucial to the manufacture of products. Sustainable design has become increasingly important in recent years, as businesses worldwide look for ways to reduce their environmental impact. In Zimbabwe, furniture-manufacturing SMEs are beginning to take notice of this trend and are starting to incorporate sustainable design practices into their operations. This paper explores the current state of sustainable design orientation in furniture-manufacturing SMEs in Zimbabwe and identifies areas where further improvements can be made. The study's contribution is valuable to the government, manufacturing SMEs, and policymakers as it provides insights into policy formulation, which is critical to environmental preservation. Thus, the research aims to assess, develop, and make recommendations to assist manufacturing SMEs in developing their operations to ensure their design and manufacturing processes conform to sustainable design principles.

Conceptual Framework

Drawing on empirical perspectives of sustainable design in SMEs, the study presents a conceptual framework depicting design competencies and resource availability. As shown in Figure 1, the conceptual framework explains that SMEs have to look at the three pillars of sustainability to achieve positive results. The design aspect is essential as it is determined by the competencies of staff who are employed by the SME and also the level of equipment and technological investment.

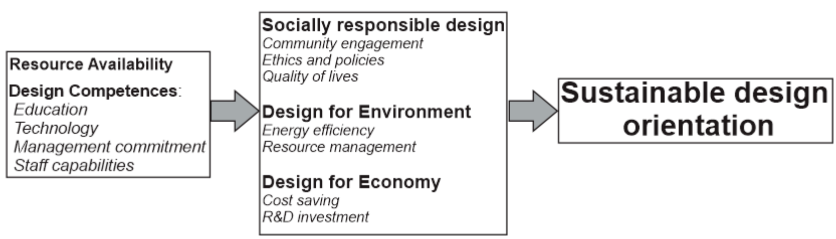

Figure 1. Conceptual framework for sustainable design orientation in SMEs.

2. Literature Review

2.1. SMEs and Sustainability

Sustainability is an interdisciplinary idea that focuses on what must be done to ensure that humans coexist peacefully with nature while also considering the needs of future generations. As reported by [21,22], implementing sustainable practices moves at a slow speed for many SMEs. SMEs have become the economic backbone of many nations, especially in emerging economies. They are crucial for reducing unemployment and act as primary raw materials and other resource consumers. An urgent need is arising to make them accountable for their carbon footprint so that these SMEs act responsibly in their environments. Many large firms have embraced sustainability initiatives to address social and corporate image, but sustainability is still poorly recognized within manufacturing SMEs [23]. Johnson [24] estimates that about 60–70% of the world's total pollution is due to SMEs. Behjati [25] further supports this by stating that SMEs in the manufacturing sector account for 64% of air pollution.

Regardless of the SME's size, it can participate in sustainable practices. However, it should be noted that SMEs have limitations, given the common challenges with SMEs [26]. SMEs do play a significant role both in emerging economies and developed economies. Thus, they need to engage in issues of sustainable development [27]. Despite the extra costs incurred, refs. [28,29] concur that SMEs benefit if they engage in sustainable practices, which might boost their competitive advantage. Sustainability, as viewed from the triple bottom line (TBL), can be defined as the combination of economic, social, and environmental concepts as critical variables that control the decision-making process in business [30]. In the case of SMEs, they need more encouragement to invest in sustainable practices [31] through evidence from other successful cases. Broccardo [32] acknowledges that the management system used in an organization determines sustainable performance. Similarly, Stawinska [27] reports that SMEs that are keen to incorporate sustainability or have done so are very few. This is attributed to the problems synonymous with SMEs, such as "Limited financial and human resources and a lack of awareness, competence, and access to appropriate tools for corporate sustainability" [26,32].

Compared to larger organizations, SMEs are more adaptable and closer to client expectations. Thus, they are expected to respond better to environmental aspects concerning their manufacturing activities [33,34]. However, this is different from the situation on the ground, as reported by [35–37]. Several factors are cited as the key challenges to environmental issues from the SME perspective. These include less knowledge or exposure to environmental issues, lack of a clear organizational role concerning the environment, and lack of customer-driven demand for environmental improvement [36]. The question is, to what extent do the customers dictate the environmental issues vis-a-vis the products they buy from the SMEs involved in manufacturing? Can these customer concerns be incorporated within the organization? If so, to what extent? Due to their size and flexibility, it is then expected that SMEs can embrace and play their role in preserving the environment for future generations. SMEs' incentive to engage in environmental problems can come from internal and external factors, though [38] posits that external influences far outweigh internal ones.

2.2. Sustainability-Oriented Innovation in SMEs

SMEs embrace eco-innovation to integrate sustainability into their business practices. Although "eco-innovation" and "sustainability-oriented innovation" are frequently used interchangeably, the former refers only to innovation's environmental and economic elements. At the same time, the latter also includes societal factors [39]. Over time, eco-innovation has expanded to cover a broader range of topics, typically linked with inventions focused on sustainability [6]. Using eco-design, design for the environment, and sustainability, Sustainability-Oriented Innovation (SOI) could be achieved by creating ecologically beneficial products, as they lower and remove hazardous materials and limit waste [38]. Eco-innovation refers to inventions that create ecological changes to support a sustainable ecosystem. It entails creating, using, or investigating new business or client organizational or management techniques [39]. Stakeholders or environmental regulations are the primary sources of motivation for SMEs to implement environmental initiatives [40]. Management commitment to adopting sustainable practices in SMEs is vital, as this drives the company's employees towards achieving one goal. In their study on SMEs in Egypt, the authors of [41] argue that the SMEs' internal capabilities affect the eco-innovation type they implement. On the contrary, ref. [42] argues that there is a dearth of studies on sustainable leadership practices in SMEs, making it difficult for these SMEs to implement sustainability in their operation.

This, therefore, implies that top management, employee dedication, or managerial attitude and motives become key in SOI. Applying practices that are motivated by sustainability can help SMEs become more competitive while also promoting sustainable development [43]. SMEs that use sustainable process innovation techniques alter how they use resources and increase their operations' overall eco-efficiency [44]. Sustainable process innovation techniques improve SMEs' overall inventive capacity and ability to adapt and meet sustainability criteria. Even though Mangla et al. [45] report that there is scant literature on SMEs that have adopted the concept of circular economy in developing countries, their study on Mexican SMEs [46] argues that the adoption of the circular economy in SMEs in emerging countries can bring positive effects to their operations.

2.3. Sustainable Design in Manufacturing SMEs

Sustainable design aims to achieve the following: produce a product with less effect or harm to the environment, produce a product that will bring profit to the organization, and produce a product that will positively impact consumers for some time. The European Commission [47] reports that the effect of a product on the environment is established in the early phases of product creation. According to [48,49], designers determine this stage. Every stage of the design process may include sustainability considerations, and several tools have been created and used to help with this effort [50]. A sustainable manufacturing system comprises three key elements: research, development, and commercialization [51]. Sustainable orientation in SMEs and collaboration capabilities are powerful determinants of green innovation adoption and mediate the effect of absorptive capacity on green innovation adoption [52]. The authors [52] further argue that organizations should design a reward system that considers environmental contributions to facilitate the environmental transition in SMEs.

Therefore, manufacturing SMEs must structure their operations in a way that will allow all three elements to be accomplished as they promote the development of sustainable economies. This is because they can produce high-caliber jobs that give residents access to better living circumstances and the opportunity to offer value to society by providing answers to market requirements and challenges not currently addressed by other businesses. There are several methods used when designing for sustainability, and these include the triple bottom line [49], the eco-design approach [53], and the product development approach [54]. Therefore, designers working for various manufacturing companies have more influence on the sustainable design aspects of the products they design during the development phase to determine the product's cost, materials, aesthetics, quality performance, maintenance, and durability. In furniture manufacturing, the eco-design approach to the design process places sustainability at the center of all design activities.

Howarth [55] argues that product designers lack awareness and consideration for the products' environment as they concentrate more on the product's technical, visual, and ergonomic aspects. For designers to develop sustainable ideas in their designs, they have to appreciate and understand their role along the sustainability chain, as they can change customer behavior. The cradle-to-cradle framework and biomimicry in design are possible pathways designers can take to achieve sustainability [56]. Given their challenges, the question is whether SMEs are ready to take such a trajectory, especially in emerging economies.

3. Materials and Methods

This study is hinged on the interpretivist research paradigm. This paradigm assumes that knowledge is subjective, as multiple realities exist [57]. The interpretive paradigm seeks a deeper understanding of participants' lived experiences, and their interaction with the researcher results in new knowledge. According to Yin [58], multiple case study research is more of an experiment where external validity is achieved through replication. The study adopted a multiple case study. Qualitative multiple case study methodology offers a way to comprehend phenomena that have received little attention from researchers [59]. The target population was furniture-manufacturing SMEs in Zimbabwe. According to the official records from the parent government ministry, 157 are registered and have been in operation for ten years or more. The chosen SMEs were selected based on the information obtained from the parent ministry and to have meaningful contributions; only those that have existed for at least ten years were chosen. Each furniture-manufacturing SME in this study serves as a case study compared to the others for replication and differentiation reasons, assuming that many case studies yield the same or different outcomes [60]. Therefore, the study adopted a multiple case study to unpack the sustainable orientation of the furniture-manufacturing SMEs in Zimbabwe. The exploratory study sought to achieve a high level of interaction with participants from various SMEs through open-ended questions and non-probabilistic purposive sampling. Some of the questions put to the SMEs include the following:

- What does sustainable design mean to you? How do you incorporate sustainability into your business practices?
- What are some of the biggest challenges you face when it comes to sustainability and sustainable design?
- What are some of the most innovative sustainable design practices you have implemented?
- How do you measure the success of your sustainability initiatives?

This research aimed to present empirical evidence on sustainability orientation in SMEs manufacturing furniture in an emerging economy, not to draw statistical generalizations from the findings.

3.1. Data Collection

This study used a relativist ontological approach and a social constructionist epistemological stance to explore the sustainability orientation in SMEs from the viewpoints of managers and designers. From a relativist standpoint, the subjective perception of reality and reality itself are indistinguishable [61]. The key participants were the SME owner or manager and the designer within that company. Data triangulation was sought through the on-site direct observations made during the design and manufacturing processes [62]. All participants were contacted before the date of the interview and gave their informed consent to participate in the study; their identities were not revealed to maintain anonymity. The study included ten furniture-manufacturing SMEs from two major cities (Harare and Bulawayo) in Zimbabwe in June 2022, as shown in Table 1. Harare is the capital city of Zimbabwe and has the highest concentration of furniture-manufacturing SMEs in the country. Bulawayo is the second largest city and boasts of being close to Lupane, where sawmills supply timber from the mukwa, rosewood, and teak. Both phases took ten days; phase one was conducted over five days, and the same for phase two. Each case was allocated a day for the two interviews and observation exercises.

Table 1. Data collection.

Phase 1-SMEs in Harare *5 SMEs (6 to 10 June 2022)*	5 SME Managers—In-depth Interviews 5 SME Designers—In-depth Interviews 5 On-site Observations
Phase 2-SMEs in Bulawayo *5 SMEs (20 to 24 June 2022)*	5 SME Managers—In-depth Interviews 5 SME Designers—In-depth Interviews 5 On-site Observations

3.2. Individual in-Depth Interviews

Twenty in-depth interviews were conducted with the furniture-manufacturing SMEs that were purposively sampled. The interviews were guided by open-ended questions that sought to explore sustainability issues from the lenses of the SME manager/owner or designer. In Zimbabwe, research into SMEs has ballooned, as they face several challenges due to their different demographic profiles, calling for the researcher to conduct a pilot study to ensure that participants understand the questions and how they respond before the study is conducted at full scale [63]. According to [64], a pilot study is "a smaller version of the main study used to test whether the components of the main study can all work together". Thus, it seeks to test the reliability and validity of the instruments in relation to the research thrust. The literature review provided a guideline for the interview questions, refined after a telephonic pilot study with one furniture-manufacturing SME that was not part of the main full-scale study. Every interview occurred inside each organization's premises, often in the interviewee's office. With the interviewees' consent, tape recordings of the interviews were made, and the whole audio recording was transcribed. In all the interviews, the participants only got to know the questions in the room to avoid predefined answers [60]. The interview questions provided a basis for discussing sustainability issues within the manufacturing SMEs and allowed further probing to reach data saturation. Various probing questions were also used to gather further information on emergent themes following the standard qualitative research methodology [65].

3.3. On-Site Observations

Observation is a complicated research method. It frequently calls for the researcher to assume many roles and employ various tactics, including using all five of their senses to gather data [66]. Observational strategies change depending on the conceptual underpinnings of the study and the position the researchers take on the continuum from observer to participant [67]. The naturalistic observation method was employed in all ten SMEs. The lead researcher observed how design and manufacturing activities were carried out in the context of sustainability in these SMEs. After obtaining consent to make the observations from the senior management for each SME case, notes were taken by the researcher for analysis. Though video recording of the observations provides an easier and faster route for data collection and analysis [67], nearly all the SMEs were uncomfortable with having videos or images taken on-site; hence, note taking was adopted in all ten cases. Yin [60] opines that one weakness of the observation method is that the researcher can understand phenomena by observing only, without asking questions. In this study, prolonged periods of observations were applied whenever needed, and notes were taken in such cases.

3.4. Summary Design Matrix Tool

The matrix shown in Table 2 was adopted to summarize the interview results. The matrix looked at sustainability considerations against the triple bottom line. The matrix elements were taken from Vicente, Moreira, and Frazao [68], inspired by the SeeeD Matrix.

Table 2. Sustainable design matrix.

	Social	**Economy**	**Environment**
Materials			
Production process			
Design process			
Waste disposal			
Management commitment			
End of life			

4. Findings

All ten SMEs who participated in this study have been in operation for the previous ten years. Their annual gross sales are given in Table 3, and it was revealed that most were profitable in their operations. Annual gross sales were approximate, obtained from the interview with the SME's manager and/or owner. Six SMEs had owner–managers as respondents, three had managers as respondents, and one had the owner as the respondent. This study also revealed that only six of ten SMEs have a research and development section or department.

Table 3. Attributes of the SMEs.

	H1	H2	H3	H4	H5	B1	B2	B3	B4	B5
No of employees	12	16	23	14	29	10	8	17	11	20
Gross sales annual (USD) '000	USD 150	USD 100	USD 50	USD 80	USD 200	USD 90	USD 100	USD 150	USD 60	USD 80
Management Interviewed	Owner/ manager	Owner/ manager	Manager	Owner/ manager	Owner/ manager	Manager	Owner/ anager	Owner/ manager	Owner	Manager
Availability of Research and Development Section	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No
Employed designer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The findings show a relationship between Research and Development (R&D) efforts and the annual gross sales of the SME. In furniture manufacturing, offering consumers new innovative or creative solutions is vital. Four out of ten SMEs had no research and development section or department. Given the size of these SMEs, investing in research and development is viewed as an extra cost that cannot be absorbed through the revenue that is going to be generated. In one case, the manager responded by saying:

> "*We cannot afford to employ an individual or team for R&D that will increase our expenditure immediately as the company's survival today is much more important than tomorrow; we rather eat what we kill today since there is too much competition*" (Respondent Manager-M03).

4.1. Design Orientation

The design aspect of the the furniture manufacturing industry is critical even in SMEs, as they seek to develop new designs that can increase their business. Table 3 shows that all the SMEs have a designer responsible for generating new ideas that will be converted into actual products by the SMEs. In Table 4, the sustainable design practices in various SMEs are also shown. In all cases, the designers had a knowledgeable, sound background in sustainability. The least qualified designer had a national diploma, whilst the highest qualified had a degree in industrial design. In the interviews with designers, they stated that knowledge about sustainability and sustainable design was part of their curriculum.

Table 4. Sustainable practices in SMEs.

Principle	Sustainable Practice
Materials	- Use durable timber - Pre-inspection of all raw materials - Recycle waste - Reduce materials used - Upcycle waste
Production process	- Latest machine/equipment - Use of Computer Numerical Control machines (CNC) - Solar backup for key sections - Energy-efficient equipment - Cleanliness of the working area - Personal protective equipment for employees
Design process	- Minimalistic in design (*less is more*) - Use of durable timber - Qualified designer - Research and development section/office - Computer-Aided Design (CAD) - R&D use offcuts and sawdust for prototype

Table 4. *Cont.*

Principle	Sustainable Practice
Waste disposal	- Selling sawdust or donating to the community - Reuse the offcuts in R&D
Management commitment	- Health insurance for employees - Invest in technologically advanced equipment - Participating in national tree planting day annually - Clean-up campaigns in the community
End of life	- Lifecycle assessment - Repair and recycle - Upcycle

They highlighted the major challenge in designing sustainable SME products as budgetary allocations to research and development. The design aspect of SMEs is also a contentious issue, as some SMEs are accused of copying or imitating other people's designs. In this study, one designer interviewee states,

> "*In design, we can be inspired by the same things found in nature and thereby end up with similar products, and the customers fail to differentiate our products and end up assuming the design is the same*" (Respondent Designer-D05).

The interviewee stated that designers always try to provide fresh design concepts and avoid exposing their companies to litigation through intellectual property infringement of a design. Additionally, given their export orientation, designers in these SMEs try by all means to be innovative and creative to keep supplying the export market with new ideas. In cases where R&D is active, one designer said they emphasize using timber offcuts in the R&D room and the sawdust when molding the prototypes before making the actual product. The results also reveal that the curriculum for higher education has managed to impart sustainability concepts to design students employed by SMEs. Though these designers have design knowledge, one major obstacle they cite is the lack of support from management in implementing sustainable ideas. In one case, the designer cited that

> "*My manager will sit down with me in a meeting to ask for ideas, and you give input or insights about sustainability from the three dimensions, but he always argues to say it is of no use in the immediate future and, therefore, cannot be implemented*" (Respondent Designer-D02).

In another case where the designer stated that he uses minimalism as a method to achieve sustainable design,

> "*Concept of minimalism can be mistaken for laziness on the part of the designer. At first, my superior used to send the ideas I had sketched to his traditional customers. It is these customers who gave positive feedback on the designs. Otherwise, it was difficult to convince him on my own*" (Respondent Designer-D07).

4.2. Environmental Orientation

The interview findings revealed a lack of knowledge and experience of managing environmental issues. The concept of taking care of the environment was raised in the case of how effluent is discharged through the storm drains, where chemicals such as paints and solvents are discarded if they are no longer needed. Because the environmental management agency (EMA) monitors effluent discharge, it was revealed that most SMEs try to ensure they are on the right side of the law by treating their waste so that it does not affect aquatic life. The findings indicate that SMEs tend to follow environmental procedures, as this is required and expected by law; otherwise, given an option, they would not bother. The observations carried out in various SMEs revealed that no clear waste disposal guidelines were followed by all the SMEs. Once something is classified as waste, employees carry it to the garbage area. In all the cases of the SMEs observed, there was no separation of the types of waste as employees cleaned or cleared the working area. In the interviews, it was highlighted that some SMEs try to use the offcuts to develop prototypes of new designs. The decision to implement sustainable design in SMEs was mainly the owner's or manager's responsibility. The designers who participated in the interviews cited that they can only advise how design can be used to promote sustainability. The unwillingness of SME managers and/or owners to implement sustainable practices was evident in this study. For example,

> "*Resources limit us; therefore, spending our time and money in such activities as sustainability will distract us from our efforts to make more profits and ensure the company survives as we want to remain operational.*" (Owner-Manager-H05).

This makes it very difficult to convince SMEs to take sustainability issues seriously, especially in an emerging market context where they face many other challenges that threaten survival. The summary of sustainable practices in furniture-manufacturing SMEs is given in Table 4. Issues concerning the end of life are not very familiar among SMEs. The moment a customer purchases a product, the attention focuses on what else they can sell to the customer.

5. Discussion

Despite the challenges of adopting sustainability practices in the furniture manufacturing sector, there are many benefits to adopting such practices in manufacturing SMEs in emerging economies. One of the most significant benefits is cost savings, as they reduce waste through efficient use of resources, thus saving money on materials and energy costs. Additionally, adopting sustainable practices can help businesses attract customers who are increasingly concerned about the environment and want to support businesses that share their values. Another benefit is an improved reputation and brand image. By demonstrating a commitment to sustainability, SMEs can distinguish themselves from competitors and build a positive reputation among customers and stakeholders. This can lead to increased loyalty and trust, which translates into increased sales and revenue and the ultimate growth of the SME into a large company.

Eco-design practices in SMEs could be a good starting point for SMEs to transform their operations into more sustainable ones. However, this should be based on leveraging traditional design criteria where they exist. Where they do not exist, introducing eco-design practices could be an added advantage, as retrofitting is unnecessary. The critical aspect of assessing the environmental performance of products through qualitative tools and performing quantitative life cycle assessments (LCAs) constitute key activities in engaging SMEs with eco-design. This engagement could support decision making regarding material selection, and product life cycle considerations, especially end-of-life considerations for disposal, reuse, remanufacturing, or recycling.

Using wooden offcut pieces for prototyping is an encouraging initiative by SMEs. The initiative should be extended to upcycling old furniture or furniture that has reached the end of its life. This can provide a niche sustainability area for furniture manufacturers because it offers an alternative to sustainable consumption by taking disposed products into a new production and value-creation cycle. The challenge is for SME designers to leverage their creative potential, upcycling used furniture materials in innovative ways to reduce and manage waste. Such an approach will disrupt the current linear economic growth model of extract, make, use, and waste, which is detached from environmental challenges. It is flawed and has resulted in environmental challenges such as pollution, climate change, and many other factors [69]. This approach will shift SME manufacturing practices to a culture that nurtures sustainability to keep the earth's productive ecosystem intact to support current lives and future generations. Oladoja [70] argues that upcycling is a promising means of reducing material and energy use and engenders sustainable production and consumption. The circular economy seeks to redefine waste not as trash but as a valuable resource with the potential for a new value creation chain in its lifecycle. Therefore, this can be a significant SME contribution to the circular economy which advocates for minimizing waste and pollution, keeping products and materials in use for a longer time, and regenerating natural systems [71].

As awareness about sustainability continues to grow, more and more manufacturing SMEs in emerging economies will likely adopt sustainable practices to transit to the circular economy. Governments and organizations are also taking steps to support these businesses by providing funding and resources for sustainability initiatives. Fonseca and Domingues [67] argue that SMEs can also implement the environmental management system ISO 14001:2015, as they envisage that it can improve sustainable practices within SMEs. However, much work must be carried out to overcome the SMEs' challenges. The government can implement tax rebate incentives based on an organization's sustainable activities over the space of a year to encourage manufacturing SMEs to be sustainable.

6. Theoretical and Practical Implications

This paper has investigated sustainable design orientation in furniture-manufacturing SMEs in Zimbabwe. The paper revealed that SMEs implement sustainable design principles more as a formality to avert contravening environmental laws. There needs to be more international motivation for their actions as it becomes more of a regulatory obligation. SMEs prefer quick business returns; thus, sustainability benefits are unclear. The furniture-manufacturing sector in Zimbabwe boasts of an abundant timber supply source; thus, the cost price of the critical raw material is low for SMEs. Given such a setup, motivation to save on material becomes a secondary issue. The study also highlights the vital roles designers play in these SMEs, as they have become champions of promoting sustainability through minimalism and upcycling in design. SMEs need to employ knowledgeable or competent staff within their operations, as they are critical in providing the much-needed skills to differentiate them from their competitors. Sustainability is everyone's responsibility, from the SME owner–manager to employees and the customers who buy from them. SMEs in emerging economies are expected to find methods of gradual implementation of sustainable practices, as these can determine their survival. The study, therefore, provides empirical evidence of sustainable practices within the context of manufacturing SMEs in Zimbabwe. This study's practical implications lie in identifying sustainable practices.

7. Conclusions

The findings of this study may be used as a roadmap by SME manufacturers as they implement sustainable design practices into their manufacturing systems so that sustainability becomes part of their procedures and plans to improve competitiveness and benefit stakeholders and the environment. Moreover, policymakers may use the research findings to create and execute environmental policies that support the owners and managers of manufacturing SMEs in Zimbabwe and other emerging economies to adapt to practices that promote sustainability, as supported by [1,6,11]. Additionally, when creating environmental regulations, it is essential to consider the characteristics of manufacturing SMEs to protect their competitive advantages and improve their sustainability, a view also shared by [48,49]. Furniture-manufacturing SMEs have opportunities to implement upcycling or promote a circular economy through their activities, and such engagements can help these SMEs to generate more income whilst promoting sustainability. In conclusion, sustainability is vital for manufacturing SMEs in emerging economies. While there are challenges to adopting sustainable practices, many benefits can help these businesses thrive in a changing business landscape. As awareness about sustainability continues to grow, we will likely see more and more SMEs adopting sustainable practices and contributing to a more sustainable future, thus transitioning to the circular economy.

8. Limitations and Further Research

The study's primary flaw was the absence of more recent data on Zimbabwe's overall number of manufacturing SMEs, as most shun registration with relevant authorities. There are many areas of future research in sustainable design in SMEs. Some of these include developing new sustainable materials and technologies, integrating sustainable design into business models and supply chains, and developing new metrics for measuring the sustainability of products and services. Future research on sustainability in SMEs should also focus on customer expectations to explain how they view or inform the design activities for sustainability to be achieved.

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Research on Affective Interaction in Mini Public Transport Based on IPA-FMEA

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Abstract: In the promotion of sustainable modes of transport, especially public transport, reasonable failure risk assessment at the critical moment in the process of service provider touch with users can improve the service quality to a certain extent. This study presents a product service touch point evaluation approach based on the importance–performance analysis (IPA) of user and failure mode and effect analysis (FMEA). Firstly, the authors capture service product service touch points in the process of user interaction with the product by observing the user behavior in a speculative design experiment, and perform the correlation analysis of the service product service touch point. Second, the authors use the IPA analysis method to evaluate and classify the product service touch points and identify the key product service touch points. Thirdly, the authors propose to analyze the failure of key product service touch points based on user-perceived affective interaction and clarify the priority of each key touch point. Finally, reluctant interpersonal communication, as the key failure caused by high risk, is derived according to the evaluation report, which leads to establishing new product service touch points and improving the overall user experience to promote sustainable transports with similar forms and characteristics.

Keywords: product service touch point; importance performance analysis; failure mode and effect analysis; affective interaction

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1. Introduction

The product–service system (PSS) design, motivated to fulfill the commands of the user, is regarded as a useful strategy to face current comprehensive development issues [1]. One of the trends of the PSS design is sustainability, which shows the great potential contribution that a strategic design approach can make to stimulating and supporting societal embedding [2]. The principle of sustainable development emphasizes the important role of public transportation: reducing empty seats in transportation can help reduce the consumption of energy, emit less greenhouse gases, and cause less pollution [3–6]. Regardless of the mode of transport, improving its utilization and efficiency is a sustainable initiative with evidence [3,7]. Vehicle miles travelled, a criterion, is defined as the miles of traveling vehicles required to meet commuting needs during a given period at the macro level [8]. All other conditions being stable, if this figure can be reduced, the traffic efficiency will increase, which equals less traffic congestion to occur and better environmental impact [9]. One of the best approaches is making full use of the seats of the vehicle in principle, and encouraging and normalizing sharing transport in practice [10]. After reviewing related research, mini public transport, such as mini buses and ridesharing, is regarded as the most balanced transport between sustainability and efficiency [11–13].

At present, the largest market for ridesharing is Europe (Mordor Intelligence, GLOBAL RIDESHARING MARKET—GROWTH, TRENDS, COVID-19 IMPACT, AND FORECASTS (2023–2028), <https://www.mordorintelligence.com/industry-reports/ridesharing-market>, [accessed on 4 April 2023].). The Global ridesharing market is expected to grow at a CAGR of 18% over the forecast period from 2022 to 2027, which shows a prosperous prospect. Due to the COVID-19 impact, although ridesharing has witnessed massive declines in demand, many believe the ridesharing market can emerge again (Ibid); therefore, it is not too late and still economical to promote ridesharing. Didi Chuxing, BlaBlaCar, Lyft, Uber, and Zimride provide various applications all over the world but similar service processes, which is the specific application scenario of this research. However, two main factors are limiting the development of mini public transport: technological factors and the passenger experience of the service [12]. These companies continue to optimize the service experience of their products, but the overall experience of users has not changed but only some details have been modified due to such great behavioral inertia, which makes it difficult to detect the starting point. Grounded in service design and interaction design, the service experience of public transport is the focus of this research.

To examine the main factors affecting the service experience of public transport passengers, a speculative design experiment by postgraduate students from the Glasgow School of Art produced a kind of driverless ridesharing vehicle prototype. Additionally, a speculative commuting ridesharing service process was proposed. Speculative design is a critical design experiment based on a virtual prototype that provides an idealized experiment object and scenario for a complex social issue [14]. Many of the large-scale speculative design experiments have yielded good results and realized some social benefits [15–17]. A report has even illustrated that the exploration of speculative design as a participatory approach to more inclusive policy identification and development in Malaysia is of evident practice meaning [17]. The speculative design is becoming a future-oriented method in theoretical design methodology to resolve complex issues and rethink the present through product design [18].

Based on the initial speculative prototype, during the study of the service users, many details that could be improved were discovered, which are comprehensive and numerous. In the face of these seemingly illogical and unsystematic details, a reasonable scientific system of analysis that can assess the importance and priorities between these various points plays the most important role. In other words, the complexity of identifying key research object units of value from complex objects and locating key items of value from complex service processes reflects the necessity for this research [19]. Therefore, the core aim of this research is to identify the main contradiction in the service process of public ridesharing and to capture the main aspects of the contradictions. Specifically, the aim is to examine the main factors affecting the passenger experience of mini public transport services and further analyze their manifestations, main causes, possible consequences, and risks of failure based on which recommendations for improvement and optimization are made to avoid the creation of pain points.

After reviewing related studies and drawing on effective methods, based on the core aim of this research, three main research methods were employed in this research: service touch point analysis, importance–performance analysis (IPA) of the user, and failure mode and effect analysis (FMEA). Service touch point analysis stages modularize and detail complex processes so that the object of study is transformed from a service process into individual points. IPA analysis quantitatively evaluates the importance and performance of each touch point to select the key touch points most deserving of focus [20]. Furthermore, FMEA, another quantitative method, analyzes the failure risk of key touch points, and those of high failure risk are supposed to be redesigned [21]. The system based on the above methods can be called IPA-FMEA, which points out the key aspects through a two-tier evaluation model. IPA-FMEA, as a kind of core-oriented assessment method, is introduced into this research, whose result will be of great guiding benefit to lead the direction of redesign and optimization.

Initial secondary research has shown that affective interactions have a significant impact on the quality of product service. Emotions are compelling human experiences and product service designers can take advantage of this by conceptualizing emotion-engendering products to promote in the market [22]. In addition to the intended functionality of the product, its affective properties have emerged as important evaluation criteria for the successful marketing of the product [23]. Therefore, an effective way to promote public transport is to improve the service experience of passengers by providing a quality space for affective interaction. Furthermore, emotional factors are likely causes of service unit failure, and it is necessary to introduce the analysis of affective interaction variables in the IPA-FMEA.

The rest of the paper is arranged as follows. The related works are shown in Section 2. In Section 3, the research scenario and method are mainly discussed, including identifying service stages and touch points, identifying key touch points by IPA, identifying failure risk of key touch points by FMEA, and clarifying the priority of touch points with high risk. In Section 4, the research result is described. Finally, a discussion of future work is proposed in Section 5, and the conclusion is presented in Section 6.

2. Literature Review

To identify research-worthy priorities from complex service processes, the three research methods, product service touch point analysis, IPA, and FMEA, presented in the relevant literature are highly informative.

2.1. Product Service Touch Point

The first task in analyzing complex processes is to simplify and modularize complex objects as much as possible. The product service touch point is a frequently cited method in the literature for classifying services by stage. It is generally accepted that product service touch points are widely present in the service process as the service recipient interacts with the product, the environment, the service, and the communication elements [24,25]. The touch points, as the basic elements of product services, make up these complex service systems whether they are linear, cyclical, or tree-like service processes. It is necessary for the designer to understand the process of service delivery to enable the design of product service touch points in greater depth [26]. One case follows the principles of experience design and uses a list of touch points to develop the concept of early mental health prevention and treatment through experimentation, focusing on an innovative built environment [27]. Another case uses product service touch points as an opportunity to expand the design perspective and embed smart technologies with conductive effects in the smart shirt design process [28].

From the existing research findings, touch point analysis is the basis and prerequisite for service design. Listing service touch points is the first step in analyzing a service process because it simplifies and systematizes the complex object, especially analyzing complex service scenarios with multiple users, multiple devices, and multiple interactions [29]. Ridesharing in mini public transport is a scenario that may involve many passengers, some products, and various interaction approaches. Thus, service touch points analysis is the practical application of this research.

However, touch points are the basic units of the service process, which needs to be evaluated. Additionally, many sources show that there is a large number of product service touch points in a service process. Thus, it is still necessary to refer to the relevant literature and to use appropriate methods for distinguishing vital ones, including IPA and FMEA.

2.2. Application of IPA and FMEA

To select some key touch points from a wide range, it is of great benefit to analyze the importance and performance of all product service touch points involved in the service process, and classify them, which is called importance–performance analysis (IPA), a method of analyzing the customer performance of products or services [30,31]. A case used IPA to explore the views of patients and nurses on the priority of rehabilitation nursing service. The IPA matrix was used to show the differences between patients and nurses in the priority of the nursing service, which provided new ideas for nursing service designs [32]. IPA is a simple and effective method that can provide decisionmakers with the index bias that affects the attention of user performance.

The results following the IPA selection are still simplistic, as the evaluation metrics only take into account the subjective perceptions of importance and performance, but ignore the objective fact of whether the touch points are prone to failure or not. Accordingly, failure analysis of key touch points is a necessary supplement. Failure mode and effect analysis (FMEA) is a systematic and forward-looking analysis tool, which is generally used to identify potential risks and safety hazards and remove problems, errors, and potential risks in the system, design, process, or service [33].

FMEA is a failure-oriented analyzing method. A case used FMEA to assess the potential failure of a medium-sized urban hospital and improve the safety of blood transfusion. The research design and method use the probability of occurrence, the severity of the impact, and the detection probability to evaluate each failure mode [33]. Furthermore, FMEA can be an endpoint research method after other analyses. An article proposes that quality function deployment (QFD) technology is used to transform customer requirements into service technology, and the priority of service requirements improvement is determined by combining FMEA. This method uses QFD and FMEA to design a local pension policy that meets the needs of the elderly, provides clear design, improves service quality, and helps to establish a local aging policy [34].

IPA and FMEA are two assessment methods with different criteria: IPA can filter out the more important points and can be used as the primary assessment; FMEA can determine the risk value of each point and can be used as the end assessment. A two-tier assessment method based on these two methods is known as IPA-FMEA.

2.3. IPA-FMEA

IPA-FMEA contains two phases, which are widely used in guiding PSS design. A case combined IPA and FMEA to evaluate user satisfaction to improve the service quality and effectiveness of a company [35]. Another case used IPA-FMEA to optimize clothing industry product design to achieve higher profitability, more environmental benefits, and social effects. [36] The examples in the literature show that IPA-FMEA can, to a certain extent, pinpoint important, low-performing, and regular objects with a high risk of failure from a complex of components. As for ridesharing in mini public transport, it is a universal, multifaceted, linear service process. Accordingly, IPA-FMEA can meet the basic needs for studying mini public transport ridesharing.

However, there are some shortcomings shown in previous research. Most cases simply take two traditional approaches and combine them in a crude way, so that it is necessary to carry out some innovations for these two methods. The traditional IPA method generally uses the average value of user importance and performance value as the classification condition in the analysis process, and the perception and attitude of different people are fuzzy and uncertain [20,32,37]. Therefore, based on the traditional IPA method, this study introduces the standard score as the classification condition of the product service touch point index to improve objectivity. The traditional FMEA method only takes mechanical failure into consideration. However, it does not take affective failure into consideration. Based on traditional FMEA, the measurement of the user tolerance area is introduced, considering the gap between the ideal service value and expected service value, which analyzes the failure risk of key product service touch points.

2.4. Preferred Method Discussion

In contrast to IPA-FMEA, there are several other assessment methods that can be used as pre-studies for service design, but these methods are more or less inadequate for this research topic. For example, a group presented a fuzzy-neural-based IPA (FN-IPA) that integrates fuzzy set theory, back propagation neural network, and three-factor theory. However, this approach is more applicable to dynamic and irregular service systems but not to stable and regular services such as carpooling. There is another example in that a group presented an FMEA method based on fuzzy methodology, which can be used to transform linguistic subjective evaluations into objective values by fuzzification and defuzzification. However, the number of experts involved in this method of assessment is so small, usually no more than six, that the results of the study depend to a large extent on the evaluators and, as a result, it is poorly represented.

With reference to the above-mentioned literature, the research methodology for this paper was determined to identify specific study subject units through service touch points analysis, and assess them according to the two-tier evaluation system of IPA-FMEA. The concept procedure derived from a combination of three methods in the literature is shown in Figure 1.

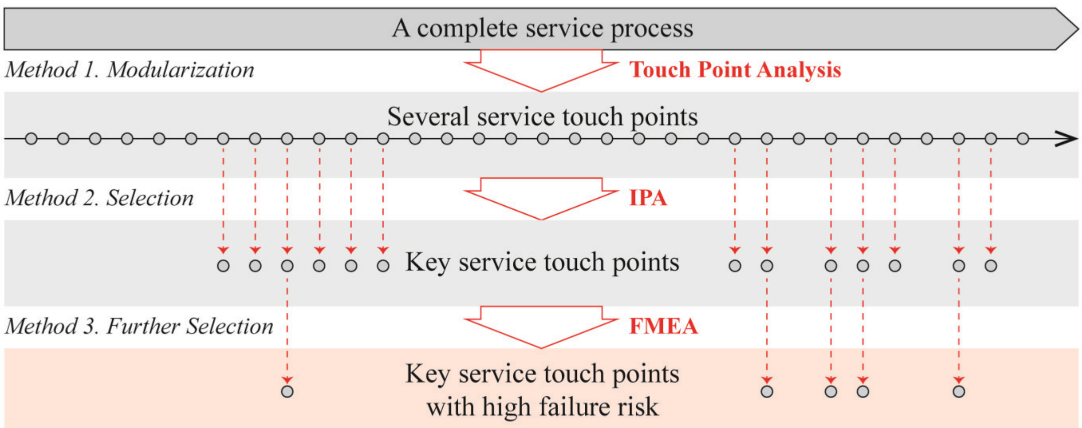

Figure 1. Analyzing methods and procedure diagram.

3. Research Scenario and Process

3.1. Speculative Experiment Scenario

To point out the core factors that make passengers dislike sharing transport and mini public transport, postgraduate students from the Glasgow School of Art held a speculative design experiment about future sustainable transport. Speculative design experiment is a popular design methodology often used to discover the key insights of future social issues [18]. As for this experiment, firstly, the group designed a kind of driverless ridesharing vehicle, as the speculative design experiment scenario. This minibus offers six seats to passengers who do not know each other, which is the basic user research scenario this paper studied, as shown in Figure 2. A variety of materials, equipment, and sites are used to compose the simulation scenario. For instance, cardboard is used to make the shell of the vehicle, and several common sorts of the chairs are used to represent the seats in the vehicle. In addition, halls, stadiums, pavements, and parks were regarded as future virtual environments for experimentation. Students, teachers, passers-by, drivers, and many other people were invited as volunteers to play the roles in those scenarios.

In addition to the physical scenarios, virtual service systems and processes have also been designed with referring to Didi Chuxing and Uber, and devised as shown in Figure 3, which is the basis of the service touch point analysis. Volunteers were asked to participate with sympathized perspectives to act out an immersive experience, including booking, waiting, checking, getting on, sitting in, and arriving. During the experience, it was of great significance to record the flow in detail and pay attention to the emotional and psychological changes of the participants. After the immersive experiment, participants were asked to complete the first questionnaire about the IPA. By inviting as many volunteers as possible or repeating the experiment more times we can obtain more primary research information. The data of the IPA below are based on the results of the questionnaire on the virtual service experience at this time. Additionally, the evidence of the FMEA below are based on observing volunteers experiencing speculative service.

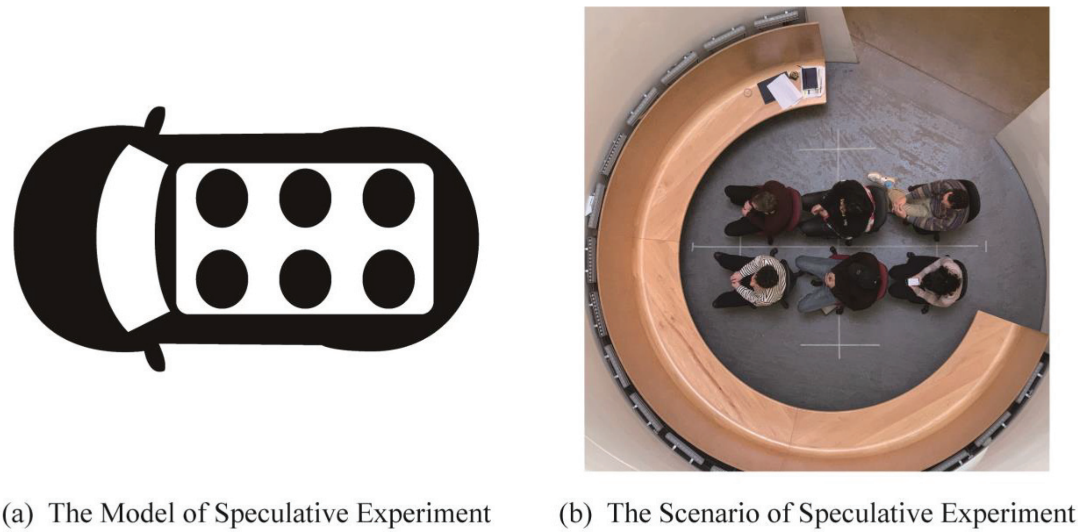

Figure 2. Speculative design experiment of driverless ridesharing vehicle.

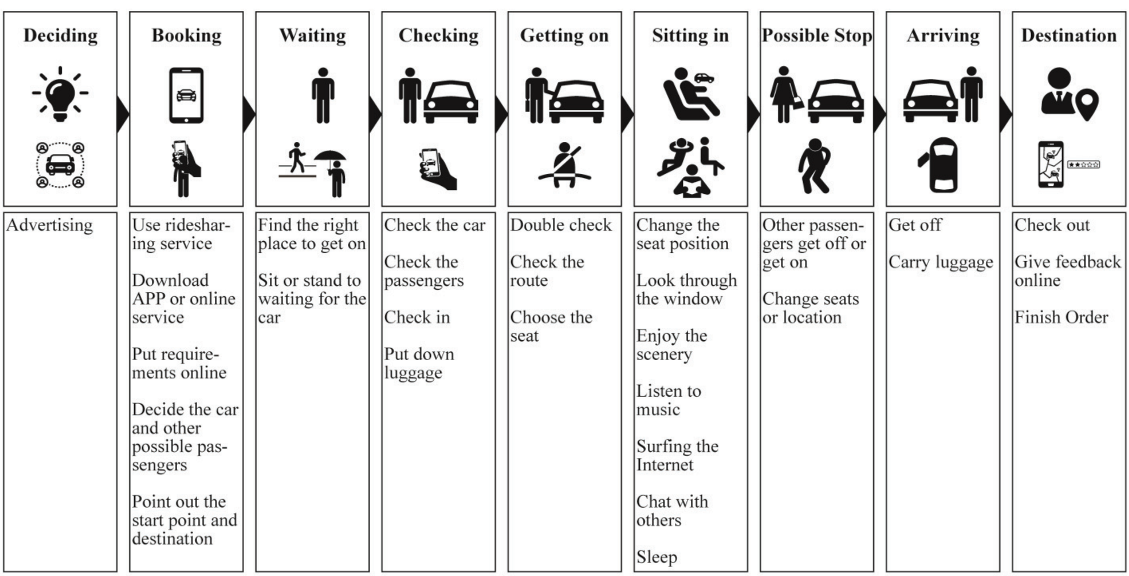

Figure 3. Speculative service process of driverless ridesharing.

3.2. Process of Four Phases

In this paper, based on the speculative design experiment above, through the analysis of user behavior identification to build public traffic service touch points in the ridesharing service process, the importance and performance of service touch points are evaluated, and the key touch points are analyzed. The failure analysis model is mainly divided into four stages, as shown in Figure 4. The specific research methods, principles, formulas, and criteria are described in detail later in this section.

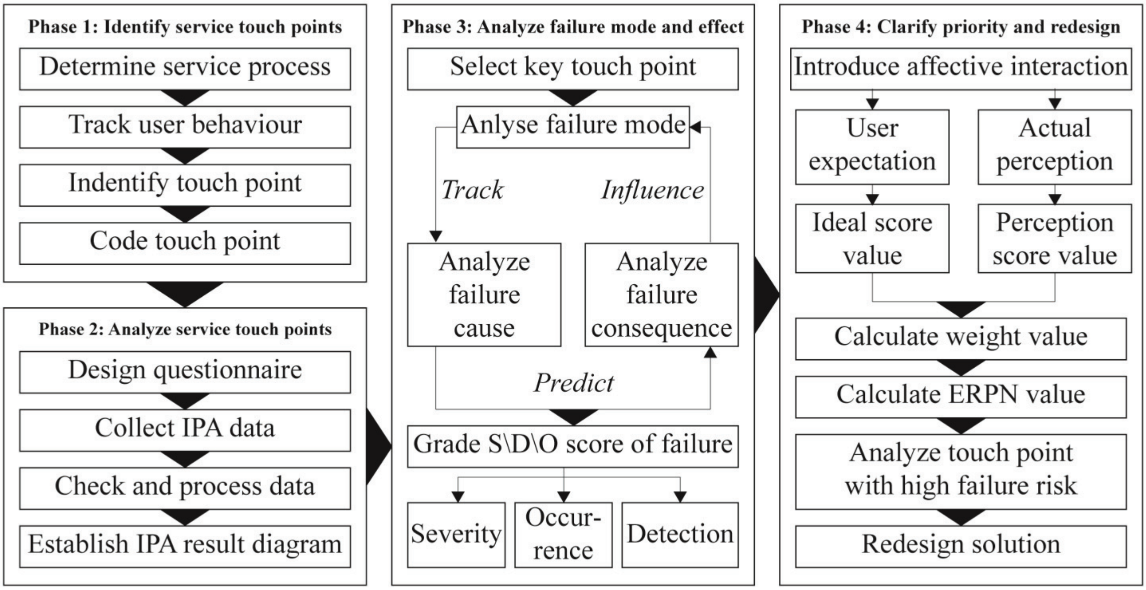

Figure 4. Research process consisting of four phases.

3.2.1. Identify Service Touch Points

In the first stage, the specific service process is determined, and the product service touch points in the whole process are identified through the analysis of user behavior. The main work in this stage is coding touch points. The product service touch points are coded as T*ij*. Suppose T = {T1, T2, . . . , T*m*} is a specific phase in a specific service process, where T*i* is the service in phase *i*, *i* = 1, 2, . . . , *m*. Furthermore, T*ij* is the *j*th product service touch point in the service process of stage *i*th, the number of sub-product service touch points in each stage is determined according to the specific situation, where *i* = 1, 2, . . . , *m*; *j* = 1, 2, . . . , *n*. After coding, the environment and medium of each contact are analyzed.

The coding system in this stage greatly contributes to reducing the complexity of the research procedures and consumed the time of the text work, which makes each service touch point shown in this paper simple and directive.

3.2.2. Analyze Service Touch Points

The first step of this stage is designing the questionnaire. All the product service touch points are used as evaluation indexes, and the questionnaire design is carried out for them. The values of importance and performance are integers in the interval between 1 and 5 [38]. The higher the value is, the higher the performance or importance of users at this touch point is. Through the questionnaire, volunteer users were asked to score the performance and importance of the product service touch point according to their own experience [39].

After retrieving the questionnaire, it is imported into the SPSS Statistics 25 software to test the reliability of the collected questionnaire data. The Cronbach's coefficient value is between 0 and 1. The larger the Cronbach's coefficient is, the more reliable the collected data are. If Cronbach's coefficient reaches 0.8, it indicates that the reliability of the scale is good.

The main body of IPA calculates the standard score and plots the coordinates. A_{pn} and A_{in} are the average score values of performance and importance, respectively, for the *n*th touch point, whose calculation is based on Formulas (1) and (2). S_{in} and S_{pn} are the values describing the standard deviation of the importance and performance score from the overall average for the *n*th touch point, whose calculation is based on Formula (3) and

Formula (4). If it is greater than 0, it means that the touch point has an above-average score and if it is less than 0, the touchpoint has a below-average score. The meanings of the other variables in these formulas are as follows: P_{mn} is the rating of the mth respondent on the satisfaction of the nth touch point, I_{mn} is the rating of the mth respondent on the importance of the nth touch point; N is the number of valid returns. MP and MI are the overall mean values of performance and importance for all touch points; SDP_n and SDI_n are the standard deviation of the performance and importance scores for the nth touch point.

$$A_{pn} = \frac{\sum P_{mn}}{N} \tag{1}$$

$$A_{in} = \frac{\sum I_{mn}}{N} \tag{2}$$

$$S_{pn} = \frac{A_{pn} - MP}{SDP_n} \tag{3}$$

$$S_{in} = \frac{A_{in} - MI}{SDI_n} \tag{4}$$

Based on the magnitude of S_{pn} and S_{in} in relation to 0, the service touch point indicators are divided into four categories [40], as shown in Figure 5. Those with a high degree of importance and performance belong to good work, marked as I; those with a low degree of importance and high degree of performance belong to a possible overkill, marked as II; those with a low degree of importance and a low degree of performance belong to low priority, marked as III; those with a high degree of importance and a low degree of performance belong to high priority, marked as IV. One should focus on the fourth quadrant, classify them as key product service touch points, and complete the evaluation of product service touch point importance performance.

3.2.3. Analyzing Failure Mode and Effect

After identifying the critical service touch point, an FMEA assessment team was formed by three service designers, three traffic management engineers, and four volunteers to classify and list the failure modes, failure causes, and failure consequences of the key product service touch points. The results of their analysis should be as concise as possible, covering a wide range of possibilities, and be significantly representative. The analysis of failure modes in this stage is the basis for the analysis of emotional interaction factors introduced later.

After the qualitative discussions reached the agreed conclusions, which are listed in the table, the severity (S), occurrence (O), and detection (D) of the product service touch point failure are scored quantitatively by the FMEA team. The higher the value, the more likely the failure is to be dangerous, which means failure is more serious, more likely to happen, or less likely to be detected [41]. The specific scoring standard [42] is shown in Table 1.

3.2.4. Clarifying Priority and Redesign

It was at this stage that the topic of emotional interaction was introduced, and it is of great significance to clarify the affective failure risk. In this study, the failure of affective interaction means that passengers have difficulty being emotionally satisfied in speculative design experiments, or are feeling negative emotions such as tension, anxiety, and unease during the experience of the service.

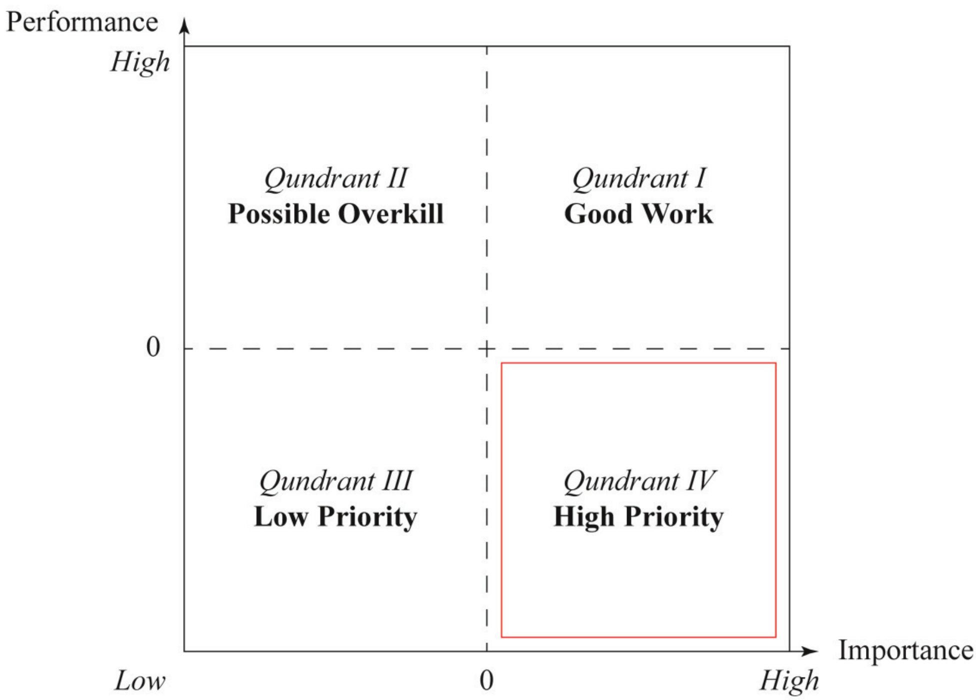

Figure 5. The four categories depend on degree of importance and performance.

Table 1. Scoring standard of FMEA evaluation.

Score	Severity	Occurrence	Detection
9–10	Great obvious impact; hard to maintain service	Probability > 30%	Non-detectable
7–8	Huge impact; difficult to maintain service	Probability ≤30%	Experience required
5–6	Moderate impact, and the service needs to be improved significantly	Probability ≤ 20%	Testing guidelines required
3–4	Minor impact, and the service needs to be adjusted	Probability ≤ 10%	Expert assessment required
1–2	No obvious impact	Probability ≤ 1%	Professional assessments and manuals required

To quantify the effects of failure of emotional interactions, the concept of user-perceived tolerance area is introduced into the FMEA. The user's expected service that affects product design can be divided into two parts: appropriate service and ideal service [43]. Proper service is the lowest service customers expect to receive, while ideal service is the highest service customers expect to receive. The tolerance area is the area formed by the gap between the appropriate service and the ideal service expected by customers. It represents the expected service within the gap range that customers can accept. The tolerance area is determined by the above two expectations, so the appropriate service and the ideal service are measured, and then the tolerance area width is calculated according to the measurement results of the two expectations, as shown in Figure 6 [43].

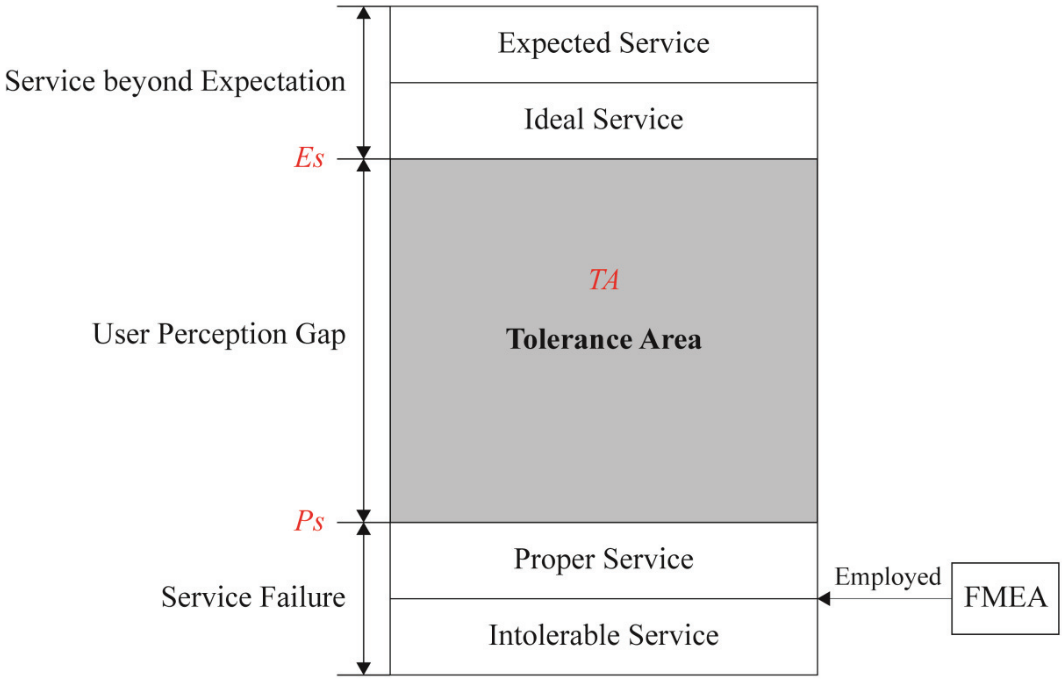

Figure 6. Model diagram of service touch point tolerance area.

Assuming that *TA* represents the tolerance area, *Es* represents the ideal service considered by the user, and *Ps* represents the appropriate service value acceptable to the user, as Formula (5) shows. *Es* and *Ps* are integers between 1 and 10.

$$TA = Es - Ps \tag{5}$$

According to the determined failure mode of the key product service touch point above, a second questionnaire is designed to investigate the user expectation and ideal value of driverless ridesharing passengers. Calculating the risk priority factor *ERPN* value of each key product service touch point by Formula (6), the greater the *ERPN* value, the greater the risk of the failure mode, and the more the need to take measures to prevent it [42].

$$ERPN = 3^{W_S \times (S - S_P)} + 3^{W_O \times (O - O_P)} + 3^{W_D \times (D - D_P)} \tag{6}$$

W_S, W_O, and W_D represent the weight of the ideal service value of the user expectation at the contact time; S_P, D_P, and O_P represent the average value of the appropriate service score of the severity, occurrence, and detection degree of the user expectation. S, O, and D are the average values of the evaluation value of each key product service touch point. The ideal service value weights W_S, W_O, and W_D were at the critical value, $ERPN = 3$. When $ERPN < 3$, users can tolerate the current service product service touch point; when $ERPN > 3$, users cannot tolerate it. The higher the *ERPN* is, the higher the priority of redesign is [42]. This stage analyzes the defects of the key risk product service touch point, or the factors causing trouble in a certain part, so as to guide the redesign of the key risk product service touch point [44].

4. Research Result

4.1. Identifing Service Touch Points

Based on the scenario and theory above, the whole service process can be divided into four stages: deciding and booking (*T1*), consisting of 6 touch points; waiting to be picked up (*T2*), consisting of 9 touch points; traveling and possible stops (*T3*), consisting of 7 touch points; and destination (*T4*), consisting of 4 touch points; 26 touch points in total, as listed in Table 2.

Table 2. Service stages and touch points of driverless ridesharing vehicle.

Stage	Environment	Touch Point	Physical Medium	Code
Deciding and Booking (T1)	indoor/outdoor	Download APP	Mobile phone, etc.	T11
	indoor/outdoor	Open APP	Mobile phone, etc.	T12
	indoor/outdoor	Point out the route	Mobile phone, etc.	T13
	indoor/outdoor	Set other requirements	Mobile phone, etc.	T14
	indoor/outdoor	Check order details	Mobile phone, etc.	T15
	indoor/outdoor	Make booking	Mobile phone, etc.	T16
Waiting To Be Picked Up (T2)	outdoor	Find a position to get on	Traffic signs, etc.	T21
	outdoor	Sit or stand to wait	Public chairs, etc.	T22
	outdoor	Check the vehicle	Mobile phone, vehicle license plate, etc.	T23
	outdoor	Check other details	Mobile phone, vehicle profile, etc.	T24
	in-vehicle	Get on	Vehicle door, etc.	T25
	in-vehicle	Choose the seat	Vehicle seats, etc.	T26
	in-vehicle	Put down luggage	Luggage carrier, etc.	T27
	in-vehicle	Sit on	Vehicle seats, etc.	T28
	in-vehicle	Check the route	Mobile phone, etc.	T29
Traveling and Possible Stops (T3)	in-vehicle	Look outside	Vehicle window, etc.	T31
	in-vehicle	Enjoy the scenery	Vehicle fragrance, etc.	T32
	in-vehicle	Listen to music	Mobile phone, earphones, etc.	T33
	in-vehicle	Use mobile phone	Mobile phone, etc.	T34
	in-vehicle	Contact with others	(NONE)	T35
	in-vehicle	Relax	Vehicle seats, etc.	T36
	in-vehicle	Others get off or get on	(NONE)	T37
Destination (T4)	in-vehicle	Check destination	Mobile phone, vehicle window, etc.	T41
	outdoor	Get off	Vehicle door, etc.	T42
	outdoor	Carry luggage	Luggage carrier, etc.	T43
	outdoor	Give feedback	Mobile phone, etc.	T44

According to Table 2, the environment of service touch points is divided into three categories: indoor, outdoor, and in-vehicle. The physical medium of service touch points includes parts of the car, such as the car seat, and user terminals, such as mobile phones. Some touch points do not require a physical medium but the atmosphere as an invisible medium.

4.2. Importance–Performance Analysis of Touch Points

4.2.1. Reliability Level Analysis

A total of 103 volunteers, including international students, university tutors, and Glasgow citizens, including walkers, bike riders, taxi users, Uber users, bus users, car drivers, and traffic police, were invited to participate in this study. A total of 103 questionnaires were sent out, and 100 valid results were returned. The interviewee group almost covers all roles in transportation, which is highly representative. The data are imported into SPSS, and the reliability test results of the scale are shown in Table 3. The Cronbach's coefficients of the importance and performance of the collected questionnaire data are greater than 0.8, which reaches the level of passing the reliability test, indicating that the reliability of the questionnaire data is high and the data are reliable.

Table 3. The Cronbach's coefficients of the importance and performance.

Objects of Reliability Test	Cronbach's Coefficient	Number of Valid Questionnaires
Importance Degree	0.828	100
Performance Degree	0.834	100

4.2.2. IPA Data Processing and Result

The results of the performance and importance ratings for each touchpoint, as a result of the statistical processing described above, are shown in Table 4.

Table 4. IPA result of service touch points.

Stage	Code	A_p	S_p	A_i	S_i	Number	Category
Deciding and Booking (*T1*)	T11	3.12	0.069268	4.49	0.255602	1	I
	T12	2.83	−0.18758	3.81	−0.35077	2	III
	T13	3.08	0.038297	4.03	−0.22708	3	II
	T14	3.38	0.390855	3.94	−0.38835	4	II
	T15	3.16	0.157974	3.8	−0.52033	5	II
	T16	3.54	0.47388	3.71	−0.49272	6	II
Waiting To Be Picked Up (*T2*)	T21	2.66	−0.35646	4.48	0.186527	7	IV
	T22	2.57	−0.39727	3.06	−1.01621	8	III
	T23	3.26	0.201638	4.88	1.298681	9	I
	T24	3.25	0.204702	4.96	3.261333	10	I
	T25	3.16	0.127556	4.66	0.522813	11	I
	T26	2.90	−0.09533	4.71	0.645302	12	IV
	T27	2.93	−0.0861	4.29	−0.03247	13	III
	T28	2.59	−0.3776	4.48	0.169329	14	IV
	T29	3.22	0.178075	3.35	−0.75014	15	II
Traveling and Possible Stops (*T3*)	T31	3.11	0.068137	4.97	2.929067	16	I
	T32	3.15	0.125738	4.65	0.393093	17	I
	T33	2.83	−0.17024	4.34	0.020225	18	IV
	T34	2.92	−0.09173	4.41	0.118384	19	IV
	T35	3.01	−0.0161	4.54	0.330323	20	IV
	T36	2.92	−0.11288	4.46	0.175843	21	IV
	T37	2.74	−0.25348	4.7	0.594071	22	IV
Destination (*T4*)	T41	2.89	−0.1338	4.27	−0.0501	23	III
	T42	3.22	0.158321	4.63	0.49562	24	I
	T43	3.02	−0.00957	4.12	−0.15721	25	III
	T44	3.31	0.298429	4.52	0.307113	26	I

The data in Table 4 were plotted according to Section 3.2.2 to facilitate the study, as shown in Figure 7.

The diagram clearly shows that touch points T21, T26, T28, T33, T34, T35, T36, and T37, which are identified as the key product service touch points in Class IV, are of great necessity to identify keys with high failure risk from these eight touch points.

4.3. FMEA of Key Touch Points

The failure modes analysis and evaluation results by the FMEA team of 10 members are shown in Table 5.

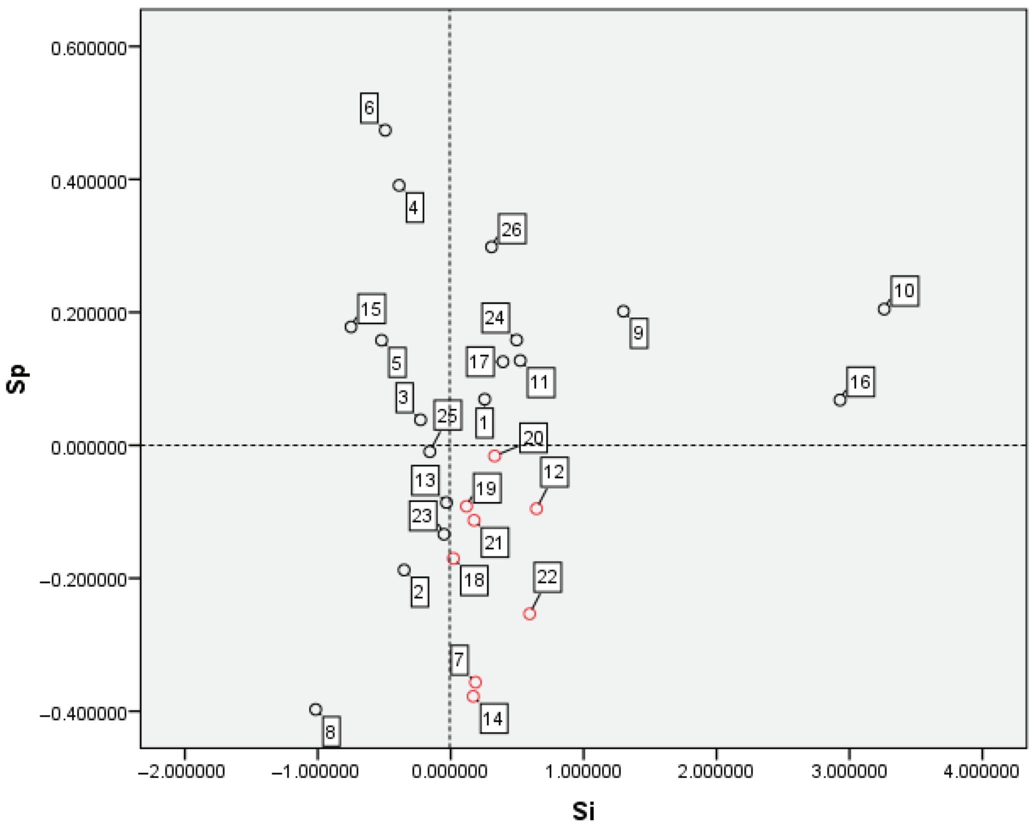

Figure 7. Classification diagram of service touch points.

Table 5. Analysis result of failure mode evaluation.

Code	Key Touch Point	Failure Mode	Failure Cause	Failure Consequence
T21	Find a position to get on	Hard to find an accurate and safe pick-up point	Unmarkable signs and inaccurate navigation	Missing leads to the extra walking
T26	Choose the seat	No preferred seat	Other passengers have chosen	Uncomfortable trip
T28	Sit on	No enough space	Other passengers have occupied	Uncomfortable trip
T33	Listen to music	Disturbed	Noise by other passengers	Less than desirable experience
T34	Use mobile phone	Privacy Crisis	Fear of other passengers seeing the phone	Boring and anxious trip
T35	Contact with others	Embarrassing atmosphere	Eye contact or body contact with other passengers	Embarrassing experience
T36	Relax	Insecurity	Fear of other passengers behaving	Worrying trip
T37	Others get off or get on	Disturbed	Need to give way for others leaving	Uncomfortable trip

According to Table 5, among these eight key service touch points, the failure of T26, T28, T33, and T37 may cause low emotions of dissatisfaction, and the failure of T34, T35, and T36 likely cause more negative sentiments, such as boredom, embarrassment, anxiety, and insecurity. To be brief, the current result of the FMEA shows that the majority of the key service touch points are related to the emotions of passengers.

The evaluation result of 10 members was aggregated and the arithmetic mean was used to describe the average level of the three criteria. The average of the scoring results for each key touch point is shown in Table 6.

Table 6. Failure evaluation result of key touch points.

Code	Key Touch Point	Failure Mode	Severity (*S*)	Occurrence (*O*)	Detection (*D*)
T21	Find position to get on	Hard to find accurate and safe pick-up point	5.2	7.1	7.4
T26	Choose the seat	No preferred seat	6.9	7.5	7.8
T28	Sit on	No enough space	8.1	7.8	7.1
T33	Listen to music	Disturbed	4.5	5.4	2.9
T34	Use mobile phone	Privacy crisis	5.0	3.9	1.9
T35	Contact with others	Embarrassing atmosphere	7.9	8.2	8.1
T36	Relax	Insecurity	7.7	8.0	7.0
T37	Others get off or get on	Disturbed	6.6	6.9	6.4

According to Table 6, the failure of touch point T28 is the most serious, the failure of touch point T35 is most likely to occur, and the failure of touch point T35 is the most hard to detect. Based on the result in Table 6, by combining the values of the three indicators and analyzing the failure effect of key touch points, further failure risk analysis is supposed to be conducted to select key touch points with high failure risk.

4.4. Introducing Affective Interaction into FMEA

4.4.1. Measurement of Tolerance Region

Based on the initial result of the FMEA mentioned above, affective failure is regarded as the main failure mode, and affective interaction is employed as a vital criterion in the second questionnaire. Through the second questionnaire, a total of 20 volunteers from the previous questionnaire interviewee group in Section 4.2.1 were invited to participate in this study, 20 questionnaires were sent out and 20 valid results were returned. These 20 interviewees cover all roles involved in the first questionnaire, which is representative to some extent. The specific evaluation results are shown in Table 7.

Table 7. Tolerance region analysis result of key touch points.

Code	Key Touch Point	*S*		*O*		*D*	
		Es	*Ps*	*Es*	*Ps*	*Es*	*Ps*
T21	Find position to get on	1	6.2	1	6.4	1	5.4
T26	Choose the seat	1	6.4	1	5.2	1	5.0
T28	Sit on	1	5.0	1	5.6	1	4.0
T33	Listen to music	1	5.4	1	5.0	1	3.2
T34	Use mobile phone	1	5.6	1	4.8	1	4.4
T35	Contact with others	1	6.0	1	4.6	1	4.6
T36	Relax	1	5.7	1	5.1	1	4.3
T37	Others get off or get on	1	5.6	1	4.0	1	3.6

The average value of the appropriate service score of the severity, occurrence, and detection of user expectation is expressed as *SP*, *DP*, and *OP*. By calculating the data in the table, we can obtain the appropriate service scores of the user's expected severity, occurrence, and detection at each critical contact time; *SP*, *DP*, and *OP* were 5.74, 5.08, and 4.31, rounded to 6, 5, and 4. The ideal service value is 1.

4.4.2. The Priority of Failure Risk

Based on the appropriate service values of the above key user severity and occurrence measures, assuming that the weights of severity, occurrence, and detection are the same, that is, the values of W_S, W_O, and W_D are all 1, then Formula (6) becomes Formula (7) [44], and the analysis result by Formula (7) is listed in Table 8.

$$ERPN = 3^{S-6} + 3^{O-5} + 3^{D-4} \tag{7}$$

Table 8. Failure risk analysis result and priority.

Code	Key Touch Point	*S*	*O*	*D*	*ERPN*	Failure Risk
T21	Find position to get on	5.2	7.1	7.4	52.36	5th
T26	Choose the seat	6.9	7.5	7.8	83.29	2nd
T28	Sit on	8.1	7.8	7.1	61.85	3rd
T33	Listen to music	4.5	5.4	2.9	2.04	7th
T34	Use mobile phone	5.0	3.9	1.9	0.73	8th
T35	Contact with others	7.9	8.2	8.1	132.10	1st
T36	Relax	7.7	8.0	7.0	60.47	4th
T37	Others get off or get on	6.6	6.9	6.4	23.96	6th

According to Table 8, the touch points with a high risk of failure are concentrated in stages T2 and T3. T35 has the highest risk of failure, which deserves more attention; T26 and T28 in stage T2 are in second and third place, followed by T36, T21, and T37. T33 and T34 have an *ERPN* value of less than 3, indicating that they have the lowest risk of failure and are of lower priority for a redesign.

4.5. Redesigning for Touch Point with High Failure Risk

4.5.1. Analyzing the Essential Causes of Failure

These touch points with a high risk of failure can be divided into two categories according to the factors that influence the affective interaction of the users. The first category is influenced by tangible physical material and the other is influenced by immaterial social distance and atmosphere. T21, T26, and T28 belong to the former category. T33, T34, T35, T36, and T37 belong to the latter category.

In terms of tangible material, the priority of T26 and T28 is supposed to be higher because of the higher *ERPN* value; furthermore, both two touch points are related to seats in vehicle. The main failure cause of T26 is that the passengers that get on early might occupy their preferred seats, which means that the passengers that get on later cannot choose their preferred seats. The seat is the primary medium of interaction during traveling, and the position of the seat has a huge impact on the emotions of the passengers. The main failure cause of T28 is that the vehicle, especially the seats inside, provides such limited space for passengers that it is easy for them to get caught up in tension, anxiety, and unease. [45] The medium for both touch points is the seat, and therefore, the seat should be considered the main object for a redesign. Reducing the differences between the individual seats in vehicles and providing more personal space for individual passengers are the main areas of optimization [46].

In terms of intangible atmosphere, the main failure causes of T33, T34, T35, T36, and T37 are all related to contact with unfamiliar strangers. The essence of these reasons is fear of socializing with strangers; in other words, insufficient social distance [45]. In terms of shared transport, deeper findings show that the so-called convenience, affordability, efficiency, and environmental friendliness that come with sharing are of less importance in the views of passengers than privacy and social distance [46]. The most remarkable pain point found after the FMEA is related to privacy and social distance, which suggests that redesigning a more comfortable affective space can provide a better ridesharing service, such as reorganizing seats to offer more independent seating spaces.

To summarize, the majority of key touch points with high failure risk are related to social phobias. From the perspective of affective interaction, the core requirements of passengers are sufficient social distance, as little interpersonal contact as possible, and a quiet atmosphere in the vehicle [45,46], which the initial prototype is not able to offer. Affective interaction is, therefore, a key focus of the redesign, and the new speculative design prototype should allow the service to meet the affective needs of the passenger and allow the passenger to feel as much affective feedback as possible.

4.5.2. Targeted Design Decision

In response to the results of the above analysis of the failure modes and causes, several possible design decisions are presented, as shown in Figure 8. The core of the solution is the redesign of the seats in the vehicle to achieve almost no difference between each seat, while providing flexible and controlled privacy for each passenger. The seat has a rotatable semi-enclosed capsule type design, and it can be controlled by the end-user device, which not only provides a limited range to avoid contact with strangers, but the optional orientation also further prevents embarrassing social scenarios. The boxy body with the larger doors and the 2×3 seats arrangement equates to more interior space.

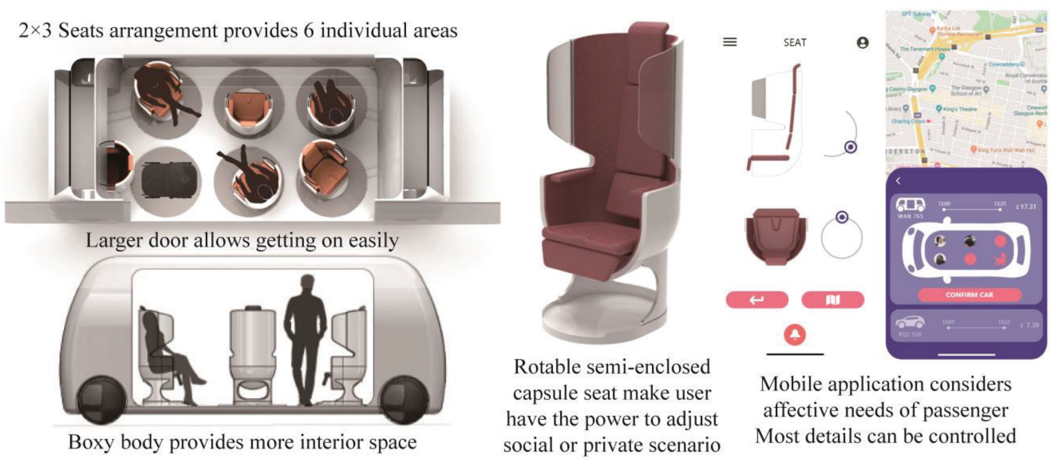

Figure 8. Targeted design decisions of driverless ridesharing vehicle.

Among the above-mentioned measures, the majority belong to the improvement and optimization of the original service touch points, as follows: the larger box-shaped carriage allows passengers to have plenty of space while avoiding contact with other passengers in the middle of the journey; larger doors on both sides make it easy for passengers to reach each seat without disturbing others; the rotatable capsule seats block some of the unnecessary social range, while giving passengers the ability to choose their orientation, making the social environment flexible and controllable; the increased interior space resulting from the reshaping of the car body, the reduced difficulty of boarding due to the enlargement of the doors, and the formation of social barriers due to the redesign of the seats are all optimizations in the form; the redesigned physical medium can serve to a certain extent to create a preferred social atmosphere for the passengers in the speculative vehicles to achieve an intangible and quality affective interaction.

Some of the solutions create a new service touch point. As mentioned above, the rotatable seats provide passengers the ability to adjust the orientation; the seat control becomes the new service touch point, whose environment is in-vehicle and the physical media are the mobile application and seat, and its main aim is to be able to accommodate the need for passengers to adjust their orientation. After the passengers adjusted to their preferred orientation, complemented by the semi-enclosed shell of the seats, the interior space is flexibly divided into individual spaces so that the affective atmosphere of most individual passengers can be met. Even for a small group of two or three passengers, the controllable seats allow them to choose to face each other without disturbing others, which can be regarded as a flexible affective interaction.

5. Discussion

5.1. Methodology Applied

The core aim of this research is to identify worth in the main aspect of great redesigning from the complex service process of public ridesharing, and to explore the factors that influence the user experience of mini public transport services, where three main analyzing methods and one core analyzing criterion were employed. Identifying service touch points, IPA, and FMEA, contributes to finding insights into complex service processes, which means that the problem of identifying the vital contradictions in service redesign is solved. With the introduction of affective interaction as the main failure criterion [47], the analysis of key touch points is carried out in a direction that focuses more on the emotional value of the user, and the results are highly informative for analyzing failure in service processes [33], which means that the problem of identifying the core aspects of vital contradictions is solved [48].

In detail, four methods were used in four stages. Service touch point analysis provides a tool to define basic individual units and modularize the complex service process. IPA is the first step to identifying key factors by setting importance and performance as two principles. FMEA provides a tool to distinguish the most impactful form of failure, which is the affective failure. Therefore, the last step is to select key touch points with high failure risk by regarding affective interaction as the most possible failure cause. The method system of these four applied methods is best named IPA-FMEA. Furthermore, this method is also suitable for other product design processes [35,36], especially for the service process with more product service touch points in the service process [42]. This method can identify the failure risk of product service touch points more quickly, and then improve the service quality.

In terms of the specific measure, this paper involved a speculative design experiment, two questionnaires, scoring, a team evaluation and discussion, and two quantitative analyses. The highlights among these may be the application of new variables in quantitative IPA analyses and applying the measurement of the affective failure tolerance region. Replacing the mean value of importance and performance with the standard score can be best characterized by a possible decrease in sample errors and systematic errors [39], which seems more objective and quantitative [40]. The indicator of affective failure tolerance may play a constructive role in quantitative estimating failure risk of key service touch points and in distinguishing the most deserving prevention from affective failure [49].

5.2. Interpersonal Affective Failure as the Main Mode

According to the final results, reluctant interpersonal communication seems to be the main affective failure mode with a high risk of service touch points. The majority of touch points related to interpersonal interaction and social distance show a high level of importance and a low degree of performance by IPA and a high risk of failure by affective FMEA. Complementary participant interviews indicate that more passengers required privacy, adequate space, and a sense of security in mini public transport [50], which might be seen to some extent as a type of social phobia [51]. Therefore, the most serious failure may be the affective failure, especially interpersonal affective failure, which means that passengers have difficulty being emotionally satisfied.

It would be feasible to try and generalize the above argument to other similar public transportation. In principle, the impact of social phobia on passenger service experience is similar in public places [50], so in practice, avoiding an awkward social atmosphere deserves to be taken seriously [52]. The core result and extension of this research is the identified main contradiction in the service process of public transport is interpersonal affective interaction. Since sustainable development requires the promotion of public transportation and one of the main measures to promote it is to improve the service experience, it is of great importance to focus on providing a preferred environment for interpersonal communication for all modes of public transportation [53], which emphasizes the important role of analyzing affective failure [47]. In addition to ridesharing, the interior spaces of public transport, such as minibuses, carriages of trains, and rooms on ships, are supposed to be considered by introducing interpersonal interaction as the main affective factor [51]. Public transportation that is friendly to social phobias should be more advantageous [49]. As for the specific forms, specific modes of transport need to be analyzed individually, but this paper does not draw on their design.

The insightful finding that interpersonal affective failure is a vital aspects affecting the ridesharing service has been proposed before. A Chinese ridesharing market research report cited the awkward emotional atmosphere inside vehicles as one of the three main factors deterring passengers from using public transport; the other two being the longer commute time and strong concerns about personal safety [54]. Research from other groups found similar conclusions [55]. Companies in China have, therefore, strengthened their policies on the supervision of vehicles and installed cameras inside them to avoid possible accidents [52]. Passengers themselves also take spontaneous steps to avoid unnecessary social interaction. However, these initiatives do not address the potential emotional failure of passengers, and as service providers, platforms do not currently have an effective solution [54]. Moreover, some studies from other countries have also found the importance of emotional interaction, but have not paid sufficient attention to it [51,52,54], which is their biggest difference with the past related literature.

5.3. Reliability of the Research Result

The results of this study are highly representative and reliable because the research scenario and model can represent mainstream ridesharing services and the research participants can represent public transport participants. The prototypes built through speculative design are the generalization of several similar applications [14,15], which means that the service logic and process are most commonly used in the current market and represent more practical commercial products. The research scenario and prototype, as the foundation of the research, are so representative that the result may be reliable to a larger extent and may help avoid some uncertainty.

Taking the uncertainty of participants into consideration, occupations or roles and the reliability of the questionnaire are important. Almost every role in public transport, such as walkers, bike riders, taxi users, Uber users, bus users, car drivers, and traffic police, was represented in the respondent sample. As for questionnaire reliability, Cronbach's coefficients in Section 4.2.1 prove that the first questionnaire is reliable. Additionally, a statistical significance test using a threshold of α = 5% aimed to evaluate whether the interviewees of the second questionnaire could represent the interviewees of the first questionnaire. The confidence levels of 25 touch points are 95% and only one touch point's significance level is approximately equal to 10%, which means that the second respondent group basically reflects the characteristics of the first respondent group [56]. Both the qualitative and quantitative analyses above confirm the reliability of the findings.

5.4. Contributions to Knowledge and Practice

To summarize, the contribution of this work mainly contains two aspects, the importance of interpersonal affective interaction in public transport and a new approach to design decisions based on IPA-FMEA.

In combination with the findings of other researchers [54,55], regardless of the form of public transport, it should be common sense and a universal standard to emphasize the issue of passenger privacy and interpersonal affective interaction while providing services.

In other design practices, the design decision method based on IPA-FMEA in this study is beneficial with the introduction of the standard score, but not the mean value and the consideration of affective failure tolerance in clarifying the priority of numerous detailed points [51,52,54].

5.5. Limitations and Further Work

All experiments were conducted using a speculative design approach through simulated immersive experiences, and although the sample of 100 participants should be highly representative, the subjective perceptions of the volunteers may still be limited [14,15]. The collection of user perceptions, mainly in the form of questionnaires and the conversion of subjective perceptions into quantitative scores through statistical methods, does not, to a certain extent, avoid the possible influence of subjective factors, such as stereotypes and biases, on the results.

The further speculative design experiment should be tested and the subsequent speculative prototypes are supposed to be analyzed by IPA-FMEA to verify the reasonableness and feasibility of this research conclusion again. On the other hand, this method requires a large amount of calculation, but the calculation model should be applied universally, and the calculation accuracy should be improved.

6. Conclusions

Due to the social benefits of improved service experience for the promotion of sustainable public transport, this research focuses on the affective interaction of in-vehicle users, which has not been thoroughly studied. Based on speculative design experiments, a novel approach, IPA-FMEA, is utilized to investigate the impact of each service touch point on the passenger experience. The findings suggest that reluctant interpersonal communication seems to be the main affective failure caused by the high risk of service touch points. Public transportation that is friendly to social phobia should be more advantageous. Despite some limitations, the information reported in this study may help to better design mini public transport service systems and create better emotional interaction environments to meet the needs of passengers. Understanding the preferences of the public and emotional perceptions of the interpersonal interaction environment could improve the design of public transport service processes, taking into account their psychological and sustainable advantages to facilitate more people choosing public transport.

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Data Availability Statement: The data are not publicly available due to the ongoing research, and the authors will continue to work with it in the future.

Conflicts of Interest: The authors declare no conflict of interest.

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Assessing the Feasibility of Practical Cradle to Cradle in Sustainable Conceptual Product Design

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Abstract: This paper delves into the feasibility of implementing Cradle to Cradle (C2C) principles in conceptual product design to achieve sustainability objectives. By developing two concept products and conducting a series of qualitative and quantitative experiments, this research demonstrates the potential of the C2C approach as a crucial guide in the design process and emphasizes its significance in creating environmentally and socially responsible products. Nevertheless, this study also highlights the challenges and limitations associated with the practical application of C2C theory and the attainment of optimal product performance. These findings underline the importance of integrating C2C principles into conceptual product design and call for further research to address the limitations of the theory and optimize its application in sustainable design. Overall, this research contributes to the growing body of literature on sustainable design and provides valuable insights into the potential benefits and challenges of adopting the C2C approach in conceptual product design.

Keywords: Cradle to Cradle (C2C); conceptual product design; sustainable design

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1. Introduction

The world's growing population and increasing demand for goods and services have led to a surge in the consumption of resources. It is projected that by 2030, over 3 billion people will have entered the middle class, resulting in an unprecedented demand for goods and services [1]. This projection has put pressure on achieving sustainable development goals, leading to a growing interest in sustainable product design and development in recent studies [2]. Environmental pollution is a major issue with catastrophic effects on the world [3], and one of its causes is the negative impact of raw material consumption on the environment, including atmospheric pollution, emissions to the natural environment, and harmful effects on biodiversity [4]. Therefore, designers and manufacturers have a critical role to play in reducing the total consumption of a product throughout its life cycle, especially during the early stages of product development [1].

Product development involves four general phases, including the "specification" phase, "conceptual design" phase, "detail design" phase, and "manufacturing" phase. The design phase has a significant impact on the environmental footprint of products, with 70–80% of a product's environmental impact being determined at this stage [5]. Moreover, 60% of product life cycle costs are determined during the conceptual design stage [6]. Therefore, it is crucial to consider sustainability aspects during product conceptual design [7]. Conceptual design is primarily a design process that involves defining the task, formulating the functions and structures of the product, seeking the most applicable combinations and principles, and identifying basic solution paths [8]. Sustainability assessment during conceptual design can identify products with minimal environmental impact while ensuring the social and economic aspects of the product [2]. Therefore, research should be conducted during the first and second stages of the product development process to achieve maximum benefits.

In 2002, the book *Cradle to Cradle: Remaking the Way We Make Things* was published [9]. The Cradle to Cradle philosophy aims to shift our focus from "doing less harm" to "doing better" [10]. While the traditional eco-efficiency approach focuses on minimizing our ecological footprint and reducing damage to the environment, Cradle to Cradle prioritizes eco-effectiveness by encouraging positive impact. Recently, various theories and methods have been developed to evaluate product environmental performance in different levels of detail [11], including carbon [12] and water foot printing [13], Life Cycle Assessment (LCA) [14], and the European Commission (EC) Product Environmental Footprint (PEF) methodology [15,16]. However, these approaches have their own definitions of sustainable products and concentrate on manufactured products, with less attention given to conceptual design. In contrast, Cradle to Cradle design approaches such as the Cradle to Cradle Certified™ Product Program [17] have not undergone sufficient scientific testing, hence the need to study Cradle to Cradle design in the conceptual design phase to fill the gap in product development processes. Although the existing literature provides some insight into the strengths and weaknesses of C2C, its scope is limited (e.g., Bakker et al. analyze the C2C principle's applicability to student design projects) [18]. Therefore, there is a need for comprehensive and reliable scientific analysis of C2C in the product conceptual design phase.

This paper aims to assess the feasibility and validity of applying Cradle to Cradle theory to product concept design through qualitative and quantitative experiments. By doing so, we propose a design method based on Cradle to Cradle theory in the product concept design phase. The feasibility of this method is verified by analyzing the choice of product concept design methods and the feasibility of concept design products based on Cradle to Cradle theory.

As depicted in Figure 1, we also regard both the C2C theory and product concept design as integral components of sustainable design. The combination of these two elements offers a novel interpretation of sustainable design theory within the context of academic research.

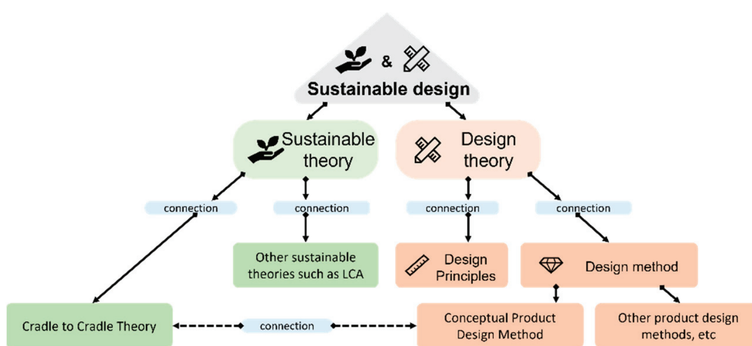

Figure 1. This article distinguishes between two distinct areas of sustainable design research, namely, sustainability theory and design theory. Sustainability theory encompasses concepts such as LCA, C2C, and PEF, while design theory focuses on the principles and methods of design. In this article, we aim to integrate C2C theory from sustainability theory with the conceptual design method from design theory. This integration can enhance our understanding of sustainable design and provide practical solutions for creating environmentally friendly products.

The previous literature has established the connection between Cradle to Cradle theory and packaging development approaches [10], demonstrating the potential for integrating Cradle to Cradle theory with other product development theories. To test the feasibility of Cradle to Cradle theory in product concept design, we propose a methodology that combines qualitative and quantitative experiments to analyze the relationship between data and concepts [19]. The research method is assessed by applying it to different product concept scenarios and comparing experimental data. The results of this study provide validation for the proposed method.

The remainder of this paper is structured as follows. Section 2 presents related research work. Section 3 outlines the research methodology and experimental design. Section 4 validates the proposed method and compares it to other experimental subjects using maize seeds as an example. Finally, Section 5 concludes this paper and suggests future research directions.

2. Theoretical Background

In this section, we provide a comprehensive overview of the current research on product concept design methods and the state of Cradle to Cradle theory and design methods. We present a detailed analysis of the existing literature on the topic, highlighting the strengths and limitations of current approaches, and identifying research gaps that need to be addressed.

2.1. Conceptual Design and Evaluation

In a 2015 article, the authors conducted a comprehensive review of 273 articles addressing product design definitions, with a particular focus on extracting several aspects from 43 articles that are pertinent to conceptual product design. These aspects encompass (1) aesthetics, (2) functionality, (3) symbolism, (4) form, (5) ergonomics, and (6) other factors [20]. This demonstrates that the pursuit of innovation across various dimensions has consistently been a focal point within the product design research field. Product novelty has long been acknowledged as a key factor in new product development (NPD) [21], with researchers increasingly concentrating on the conceptualization and measurement of innovation in recent years [20]. Conceptualization encompasses both the theoretical significance of product design in terms of definition and the early stages of product development, such as the testing of prototypes or product concepts, which hold considerable value [20].

In previous research, product concept design approaches incorporating aesthetic, functional, and symbolic elements have been proposed [22]. Although the methodologies employed in various studies differ substantially, the majority of authors concur that product innovation represents a multi-dimensional concept. Consequently, most new products undergo proof of concept and prototype testing and evaluation before being launched into the market [23].

Concept design evaluation is a critical aspect of the product development process, as it directly affects the quality, cost, and desirability of the final product [24,25]. However, concept evaluation is a complex, multi-objective decision problem, as the objectives of two subjects, technical and economic characteristics of the product, are in natural competition. One of the major challenges in concept selection is to find a solution that obtains the maximum combined value under conflicting objectives [26,27].

Various approaches to conceptual design evaluation exist, including solution evaluation techniques that combine customer needs and designer limitations proposed by Tiwari et al. [28], visual analysis methods based on the Kano model suggested by Atlason et al. [29], and a focus on demand from different stakeholders in the innovation diffusion process proposed by Cantamessa et al. [30]. Although numerous research approaches and theories in conceptual design methods exist, some are better justified by data or quantifiable research methods such as parameters. For instance, the PDS-behavior-structure conceptual design model proposed in 2016 [31] is a data-supported method that helps determine reasonable conceptual design solutions for multi-disciplinary-oriented complex product systems. The evolutionary game-based product concept design approach proposed in 2019 [32] discusses how the concept in the product development cycle decisively affects cost and performance. In the same year, binary semantics was proposed [33], with a case study used to illustrate the method. Considering the role of information ambiguity in product concept design, an intuition-based fuzzy group decision product concept design method was suggested. In 2019 [34], a CBDT-TRIZ model was established to help design engineers make informed decisions quickly, thus speeding up the design process. Another conceptual design approach based on conceptual knowledge modeling and eye-tracking data analysis was proposed in 2019 [35] to analyze the factors influencing the individual-level transfer of engineering knowledge. In 2020, the use of group decision making and intuitive fuzzy preference relationships was proposed to quantify conceptual schemes that consider sustainability attributes [36]. However, building validation models quickly and using strategies such as group decision making is not an easy challenge and has the potential to increase design costs. For example, in 2012, the authors of [37] discussed how using the wrong representation at the wrong stage of design development can lead to inefficiencies and costly redesigns.

In contrast, simple and general analytical methods that are used in all fields, such as quantitative and qualitative studies, offer great advantages. In recent decades, these research methods have been applied to studies in the fields of psychology [38], medicine [39], and education [40], respectively. In a 2016 article [41], quantitative research was seen as providing "hard", "factual" data, while qualitative research was described as softer, providing more in-depth insight. Although quantitative and qualitative research methods are widely used in various fields, little is known about the feasibility of discussing C2C theory in the context of conceptual product design. As products and product services become increasingly complex [42], co-innovation and competitive design-driven innovation [43] will be pursued through multi-disciplinary collaborations.

2.2. Cradle to Cradle (C2C)

The publication of the book *Cradle to Cradle: Remaking the Way We Make Things* [9] marked a significant shift in the theoretical study of eco-efficiency. Cradle to Cradle (C2C) theory [9] proposed in 2005, consisting of three principles—waste as nutrient, use of renewable energy, and promotion of diversity [44]—is essential in defining eco-efficiency and life cycle. The research based on C2C theory extends to various products and systems, including the conversion of materials into nutrients proposed through biometabolism and technometabolism in 2007 [45], recycling production methods developed in 2019 [46], and the assessment of the environmental potential of urban pavements in 2021 [47]. However, the effectiveness of C2C-guided formation in the conceptual design section, which is often skipped in most studies, should also be studied.

C2C theory is currently mainly applied in the field of strategy analysis and circular economy. For instance, a circular economy and C2C were used for university teaching in 2018 [48], environmental adaptation strategies based on ecological goals were proposed in 2019 [49], and a literature review on the application of a circular approach to education for sustainable development was conducted in the same year [50]. Moreover, Cradle to Cradle production solutions were proposed for used furniture in 2020 [51], while C2C was proposed as a product design concept rooted in "healthy" material circulation to address the disadvantages of a circular economy in 2021 [52]. Although there are few methods to directly evaluate the feasibility of C2C theory, it is often used as a guide to analyze cases.

The current study explores the connection between C2C theory and product conceptual design. In 2010, it was noted that the C2C approach can serve as a complementary method in the design process and offer guidance for conceptual product development. However, it is prone to dogmatic errors, making it unsuitable for all product designs [53]. In contrast, utilizing experimental and numerical analysis to establish a proof-based conceptual product design process guided by the conceptual design approach ensures the scientific rationality of solution formation and output. This approach helps to enhance the efficiency and quality of product design [54].

According to a 2019 study [55], the new knowledge society will undergo changes along with new cognitive differences. Exploring product conceptual design before implementing a landing solution will be an opportunity for future innovation. This study aims to address this issue by verifying the value and feasibility of C2C theory in concept design before product landing, using various research methods such as qualitative and quantitative. It is also proposed, as in 2019 [35], that the rational reuse of past experiences can facilitate product innovation. Moreover, a 2020 study [56] suggests that the importance of cross-domain knowledge for product innovation design is continuously increasing, including the reorganization, transfer, and transformation of multi-domain knowledge. Emphasizing the conceptual design phase of research can also promote innovation.

3. Methodological Approach

In this section, we propose an evaluation scheme based on qualitative and quantitative experiments to determine whether Cradle to Cradle (C2C) theory can guide the design of a good concept product, and we present the limitations of the method. The feasibility of C2C theory in product concept design is evaluated through a data analysis-based product concept design approach combined with relevant quantitative and qualitative experiments, with the experimental analysis-based scheme applied to determine the feasibility of the theory more comprehensively in multiple directions.

The framework diagram of this study, shown in Figure 2, is based on a combination of qualitative and quantitative analysis methods, a product concept design approach based on data analysis, and the principles of waste and nutrients in C2C theory. To avoid the subjective, relative understanding that occurs in qualitative-based analysis, especially for qualitative methods that assume only partially objective descriptions of the world that can be understood in various ways [19], we use data analysis such as numerical modeling, which is more likely to receive the influence of experimental data and rigor of experimental settings. Finally, we combine these two approaches to create an effective and flexible research methodology, which provides more knowledge and insight into the research topic [57].

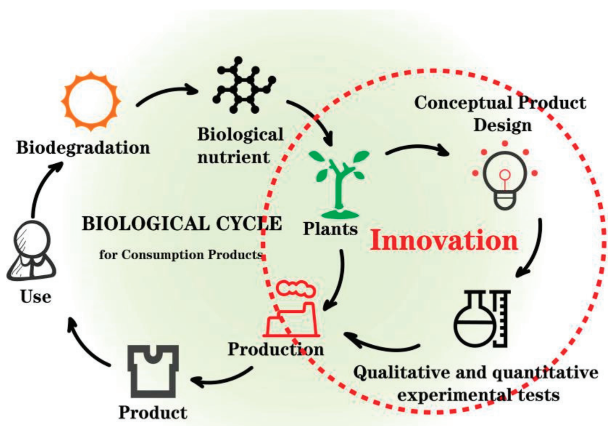

Figure 2. This paper employs a combined qualitative and quantitative experimental approach to validate the feasibility of integrating C2C theory with conceptual product design. The qualitative and quantitative experiments provide valuable data support for the theory, while the theory provides a logical framework for the experiments. What sets this study apart is the approach taken, which begins with the key principles of C2C theory and combines them with conceptual product design methods to discuss the feasibility of the theory using a qualitative and quantitative experimental validation method.

Our current research aims to further understand the testing and corroboration of C2C theory by qualitative and quantitative experiments during conceptual product design. Therefore, we will attempt to better explain the importance of C2C theory for the product conceptual design phase. Here, we explain the validity of the guidance of C2C theory for concept product design from experiments such as qualitative and quantitative. The overall sense of effectiveness depends on the value of the number of experiments and the different types of experimental approaches. However, the current study explores the implications of C2C theory in the product concept design phase.

From this perspective, we hypothesize that if the setup of qualitative and quantitative experiments is influenced by the norms, rules, and conventions of different fields for experiments, then the presentation of the experimental results differs depending on the field of expertise. In this regard, we expect designers to pay more attention to the rationality of the experimental approach argumentation and the impact on theoretical innovation. In contrast, research by means of data analysis, such as building numerical models, is more likely to receive the influence of experimental data and the rigor of experimental settings. On the other hand, innovation in theory is likewise based on different understandings of multiple identical knowledge, which is in line with [35], who suggested that the rational reuse of past experience can facilitate design innovation, i.e., innovation is about the scientific yet logical use of existing knowledge.

A practical and strategic expression of the eco-efficiency concept of "Cradle to Cradle" defines a framework for designing products and industrial processes so that living systems can be used for human purposes and safely returned to the environment for use in biological processes that do not cause immediate or ultimate harm [9]. To achieve these goals, we designed two conceptual products (hollow maize seeds and absorbing ball) using C2C principles and examined their responses in quantitative and qualitative experiments.

3.1. Design of Conceptual Products

In this section, we will discuss how the theory of C2C, which envisions a future of environmental sustainability, has been incorporated into the design of our concept product [58]. A 2017 article published in Springer Press's Life Cycle Assessment issue elucidated that the objective of C2C is to exert a positive influence on the environment, encompassing human well-being [59]. To attain this goal, three fundamental design principles ought to be adhered to throughout the process: waste as a resource, utilization of current solar income (renewable energy), and the celebration of diversity [17,59]. Consequently, our design also follows these three key principles:

1. The principle of waste equals food, which requires that all materials and emissions be considered beneficial to the environment or the technosphere. Our product has been designed to be harmless to human health and sustainably recyclable, with no waste generated and all outputs serving as inputs to other systems. This allows us to establish closed-loop systems based on these cycles.
2. The principle of enhancing renewable energy sources, which we consider essential to effective design. We have maximized the use of renewable energy sources wherever possible.
3. The principle of focusing on diversity, which is a key to innovation in designing technologically diverse products that avoid a "one-size-fits-all" approach.

Our concept product is designed to absorb food, with potential uses including obstructing food absorption and aiding in weight loss [60]. The increasing rate of obesity is a global public health problem, particularly among girls who are struggling to achieve a socially acceptable ideal body [61,62]. Long-term or chronic attempts to lose weight can have serious consequences on the physical and mental development of young people, with female dieters being more likely to suffer from nutritional deficiencies, growth retardation, menstrual irregularities, delayed sexual maturation, irritability, sleep disturbances, and poor concentration [62,63]. A three-year follow-up study conducted in the United States [64] showed the most commonly employed methods for weight loss among adults were exercise and maintaining healthy eating habits.

Our concept product is designed to allow normal eating behavior without the need for dieting. Rather than eating less food, our product absorbs the "extra" food, which is expelled from the body during the digestion process. This approach helps users solve the problem of eating less food and dieting, making our product more appealing to users.

Figure 3 elucidates how the conceptual product is utilized by users and delineates its role in each stage of human digestion. Meanwhile, Figure 4 exhibits the packaging and product rendering of the conceptual product under examination.

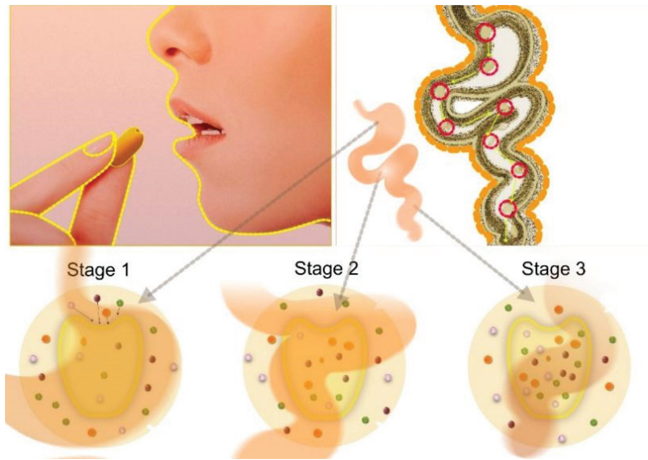

Figure 3. The product undergoes ingestion and enters the human digestive system. During the first stage, the product and food pass through the stomach, where the vigorous movements break food down into smaller particles. Subsequently, the product gradually absorbs some of the food. In the second stage, the product traverses the small intestine, where the food undergoes further degradation due to the coordinated movements of the small intestine. The external cellulose of the product serves to prevent the villi of the small intestine from coming into contact with other digestive fluids and food that may be absorbed by the product, while allowing the product to absorb more food. Finally, the product enters the large intestine during the third stage, where peristalsis expels it from the body along with the absorbed food. Therefore, the workflow of the product obviates the need for users to restrict their diets to achieve a reduction in food absorption.

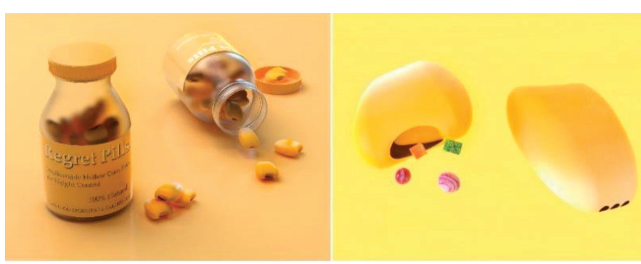

Figure 4. The above figure illustrates the structural blueprint of a conceptual product. The upper part of the product features an angled aperture, which facilitates food intake, while the lower end has multiple small orifices to discharge digestive enzymes. Upon entry of food into the product, the downward sloping aperture creates a unidirectional pathway, making it difficult for the food to escape. Consequently, a state of ease in food ingestion but difficulty in excretion ensues. The bottle product, in turn, is a consequence of the packaging design.

In the following sections, we will discuss the research that has been conducted in three areas: material selection, structural design, and derivative concept products of our design, all of which are in line with the principles of C2C.

3.1.1. The Application of Cradle to Cradle (C2C) Theory in Material Selection for Concept Products

According to the principles of Cradle to Cradle (C2C) theory, products should be designed in a way that they can be recycled sustainably and be health-friendly to humans [65,66]. Sustainable design using raw materials from nature is exemplified in Indonesia, where designers have utilized pineapple leaf fiber as a fashion material [67]. Similarly, the concept product design discussed here utilizes maize seeds, a common plant from nature.

Maize (*Zea mays*), also known as the queen of grains, is a miracle crop and the third-most important cereal crop in the world after rice and wheat [68]. The pericarp of each maize kernel, which makes up approximately 7% of its weight, contains fiber cells rich in phytochemicals [58]. The cellulose in the pericarp protects the kernel from being digested by the body, making it a natural design material without damaging the epidermis.

The selected material for the concept product design is maize seeds, which takes advantage of the fact that maize is not easily digested by the human body. Additionally, the starch in sun-dried maize undergoes hydrolysis during storage, resulting in a hollowed-out internal starch in maize seeds that contains very little starch. This provides a solid research basis for experimental validation of the concept product [69].

The flow of maize seeds in nature is similar to the flow of biotrophs, or substances that optimally flow in the biological metabolism of organisms [45]. Biotrophs can include natural or plant-based materials, as well as biopolymers and other potentially synthetic substances that are safe for human and natural systems. Biological metabolism encompasses resource extraction, manufacturing and client use, and the eventual return of these materials to natural systems, where they can be transformed into resources for human activities [45]. Therefore, the selection of maize seeds aligns with C2C theory's principles of enhancing renewable energy.

3.1.2. Guiding Conceptual Product Structure Design with Cradle to Cradle (C2C) Theory

The proposed concept product is primarily designed to absorb food efficiently while preserving the material's integrity. Therefore, it is critical to devise a structural design that enhances food absorption while inhibiting its efflux.

To address this challenge, we propose a novel design that features a downward sloping opening at the top of the product. As food enters through the opening, it becomes ensnared by the sloping surface, preventing any attempts to escape. The product structure's bottom is hollow and includes several small openings to drain water from the absorbed food, while minimizing the presence of digestive juices or other liquids. Figure 5 presents the two conceptual product prototypes designed by our research team.

Our design is carefully crafted to improve food absorption while maintaining the material's integrity, in line with the principles of "Cradle to Cradle" theory. By minimizing waste and maximizing resources, our concept product offers a sustainable and efficient solution for food absorption.

3.1.3. Designing Concept Product Derivatives through Cradle to Cradle (C2C) Theory

Following the fundamental principles of C2C theory that emphasize the recognition and appreciation of diversity, we developed a conceptual design based on maize seeds along with a unique derivative featuring an angled opening at the top. Figure 6 depicts the derivatives of the four conceptual products designed by our research team.This was performed to ensure consistency in the primary functions of the experiment. The main objective of the experiment was to evaluate the uptake capacity of the maize seed-based derivative and compare it with that of the maize seeds. Additionally, we aimed to determine whether the derivative could outperform maize seeds in terms of uptake quantity. Figure 7 presents the optimal product selected from the derivatives of the four conceptual products after conducting a comprehensive multi-dimensional evaluation.

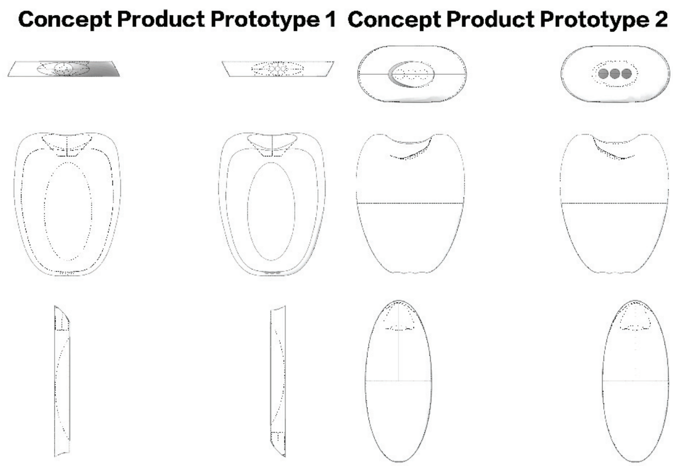

Figure 5. Six views of two conceptual product prototypes based on maize seeds are displayed. These designs aim to retain the natural product's appearance, potentially enhancing user acceptance psychologically.

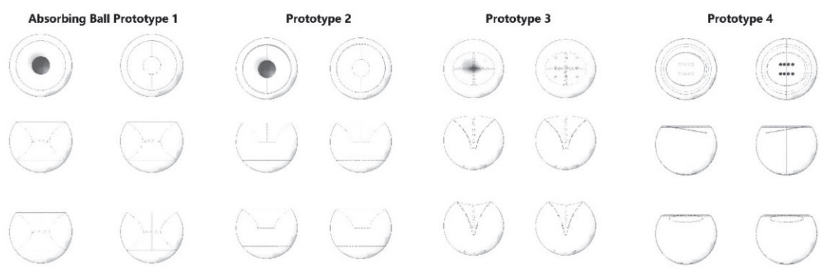

Figure 6. In accordance with the C2C principle of valuing diversity, the design of the derivative ball departs from the original concept product. As a product with conceptual diversity, the purpose of the derivative ball is to maintain the functionality of the concept product while enhancing its performance. To that end, four derivative ball were designed, with each following the principles of C2C theory.

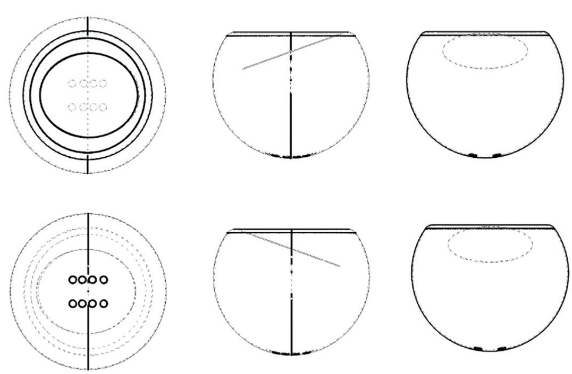

Figure 7. After careful evaluation of four derivative ball designs, we chose the final experimental prototype. Our evaluation was based on the complexity of the 3D printing process and the internal space of each prototype. Ultimately, we determined that Prototype 4 was the optimal choice.

3.2. The Purpose and Methodology of Experimentation on Concept Products and Derivatives

The methods of material preparation, direct seed experiments, transplantation experiments, and statistical analysis mentioned in 2006 [70] are primarily used in horticultural science research. Given that this study involves the selection of natural crops and similar data analysis, traditional research methods [31] such as the proposed conceptual design model to support product design are not applicable. Instead, the chosen research method involves experimental and data analysis. Furthermore, this approach emphasizes the influence of the conceptual model on the product design. In contrast, direct seed and transplantation experiments provide better analytical ideas for iterative product design. The experiment was mainly conducted indoors, and its purpose was to verify whether the conceptual product, hollow maize seeds designed using C2C theory, and its derivative product, absorbing ball, could absorb different types of foods.

One of the challenges addressed during this study was how to confirm the validity of the combination of the two theories through data argumentation. One way to overcome this issue is the proposed process of applying theory and experiment to conceptual design in [71,72]. Additionally, in 2019 [34], a method for justifying the rationality of the combination was proposed.

Furthermore, the research process is crucial for selecting conceptual design solutions, and in 2019 [73], a decision-making method was proposed to evaluate the relative equilibrium of conceptual designs. This method addresses the problem of option selection in conceptual design. However, the current study primarily focuses on the analysis of experiments and data, rendering this method irrelevant. Nevertheless, solution selection remains a crucial component in conceptual design.

This paper employs two methods to quantify the combinability between the two theories. Firstly, direct seed experiments are combined with quantitative and qualitative experiments [74] in horticultural science research [70] to demonstrate the feasibility of selecting materials for the conceptual product. Secondly, the rationality of the concept product is argued through transplantation experiments and derivative experiments. Additionally, since there are ethical issues regarding the validation of the concept product through human experiments, this paper uses the above two methods to bypass human experimentation and validate the study's content.

3.3. Design of Quantitative and Qualitative Experiments

In general, quantitative studies involve predetermined data collection and require the researcher to carefully describe variables that can be computed numerically. This approach is often viewed as reductionist, where the truth is reduced to a number [19], and assumes that variables can be measured objectively. In this approach, the study of cause-and-effect relationships between or among variables is typically of interest [19].

To set up a quantitative experiment for hollow maize seeds, three small groups of experiments were established. On the other hand, qualitative studies have flexible designs and measurement of variables that depend on the context of data collection. Qualitative methods assume that only partially objective descriptions of the world can be produced and thus can be understood in various ways [19]. Therefore, to enrich the variety of experiments, the qualitative experiments were divided into two groups, which contained six small groups of experiments.

Additionally, a qualitative experiment group was established for the derivative absorbing ball, which included two small groups of experiments. Figure 8 illustrates the design of both quantitative and qualitative experiments.

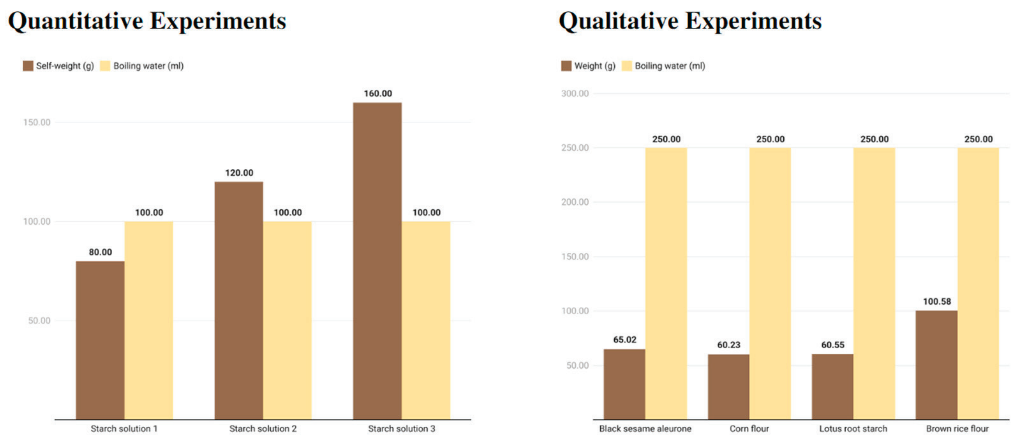

Figure 8. The design of qualitative experiments for the concept product involved four different solutions: black sesame pastes, maize paste, lotus root powder, and brown rice flour. Furthermore, the design of quantitative experiments for the concept product involved three different concentrations of starch solutions.

3.3.1. Preparation of Experimental Materials

Prior to conducting the experiments, the materials for both the quantitative and qualitative studies were carefully selected and prepared. For the quantitative experiments, starch was used as the experimental material. For the qualitative experiments, four different materials were selected, namely, lotus root powder, maize paste powder, black sesame paste powder, and brown rice powder.

Furthermore, several essential tools and equipment were prepared, including plastic bottles for rotation, a motor, an electronic scale, a measuring cup, a rotating fixed structure, a rotating track, an adjustable power supply, tweezers, and a number of hollow dried maize. This ensured that the experiments were conducted accurately and effectively.

3.3.2. Experimental Introduction—Experiments on Hollow Maize Seeds Using Quantitative and Qualitative Methods

- Quantitative Analysis Experiment—Starch Solution Experiment

The purpose of this quantitative analysis experiment was to investigate the ability of hollow maize seeds to absorb different concentrations of solutions prepared from the same material. Three experimental groups were established, with concentrations of 80 g/100 mL, 120 g/100 mL, and 160 g/100 mL. The experimental solutions were created by mixing starch with water at room temperature. The independent variable was the experimental time, with intervals of 5 min, 10 min, 15 min, 20 min, and 25 min. The dependent variable was the weight of hollow maize seeds after absorbing the solution. The experimental subject was hollow maize seeds, with a total of eight seeds used in the experiment.

- Qualitative Analysis Experiment—Multiple Solution Experiment

In this experiment, the purpose was to verify whether hollow maize seeds have the ability to absorb solutions of similar concentrations prepared from different materials. Four groups were created with different ingredients: black sesame paste powder (65.02 g/250 mL), maize paste powder (60.23 g/250 mL), lotus root powder (60.55 g/250 mL), and brown rice powder (100.58 g/250 mL). The experimental solutions were prepared by mixing water at room temperature with each ingredient and stirring. The independent variable was the type of ingredient, while the dependent variable was the weight of hollow maize seeds after absorption of the solution. The experimental subject was hollow maize seeds, with a total of six seeds used in the experiment.

- Qualitative Analysis Experiment—Viscous Solution Experiment

In this experiment, the purpose was to verify whether hollow maize seeds have the ability to absorb viscous solutions prepared from different materials. Two groups were created with different ingredients: maize paste powder (50.03 g/250 mL) and lotus root powder (50.05 g/250 mL). The experimental solutions were prepared using 100 °C water mixed with the respective ingredient and then cooled for 1 h prior to the experiment. The independent variable was the type of material, while the dependent variable was the weight of hollow maize seeds after absorption of the solution. The experimental subject was hollow maize seeds, with a total of six seeds used in the experiment.

3.3.3. Experiment Introduction—Experiments on Absorbing Balls Using Qualitative Methods

- Qualitative Analysis Experiment—Viscous Solution Experiment

The purpose of this experiment was to investigate whether the derived structure ball have the ability to absorb viscous solutions and whether they can outperform hollow maize seeds in terms of absorption multiplicity. Two experimental groups were tested using maize paste powder (50.00 g/250 mL) and lotus root powder (49.95 g/250 mL) solutions, respectively. The experimental solutions were prepared by mixing different ingredients with 100 °C water and stirring, and then cooled for 1 h prior to the experiment.

The independent variable in this experiment was the type of material used (maize paste powder, lotus root powder), while the dependent variable was the weight of the derived structure ball after absorption of the solution. The experimental subject was the derived structure ball, with four ball used in each experimental group.

This research may have significant implications for the development of more effective and efficient absorbent materials in the future.

3.3.4. Solution Proportioning for Experimental Design—Quantitative and Qualitative Methods for Studying Hollow Maize Seeds

- Starch Solution Experiment

The design of the starch solution experiment is illustrated in Table 1, where we prepared three different concentrations of starch solutions for the purpose of quantitative testing.

Table 1. Experimental Solution Proportioning in Quantitative Analysis.

Material Weight/Material Classification	Starch 1	Starch 2	Starch 3
Self-weight (g)	80.00	120.00	160.00
Boiling water (mL)	100	100	100

- Multiple Solution Experiment

The design of the multiple solution experiment is presented in Table 2, in which we prepared four distinct solutions for the purpose of qualitative testing. Diverse ratios are established based on the water solubility of the constituents, with the intention of attaining the utmost uniformity in the concentration of the solution.

Table 2. Experimental Solution Proportioning in Qualitative Analysis.

Material Weight/Material Classification	Black Sesame Aleurone	Maize Flour	Lotus Root Starch	Brown Rice Flour
Self-weight (g)	65.02	60.23	60.55	100.58
Boiling water (mL)	250	250	250	250

- Viscous Solution Experiment

The design of the viscous solution experiment is illustrated in Figure 9 and Table 3, wherein we prepared two distinct solutions for the purpose of qualitative testing.

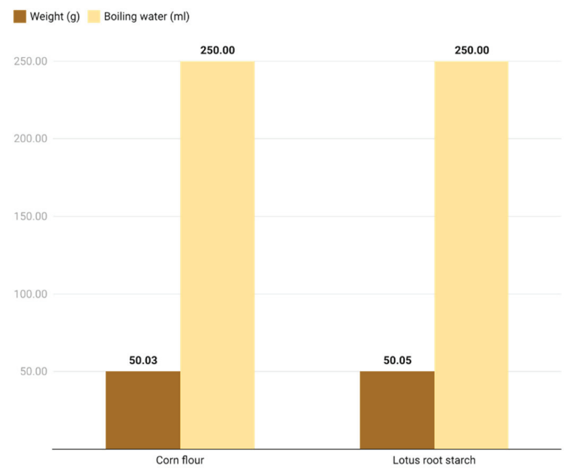

Figure 9. The experimental procedures were carried out utilizing a maize paste solution with high viscosity and a lotus root powder solution.

Table 3. Experimental Solution Proportioning in Qualitative Analysis.

Material Weight/Material Classification	Maize Paste Solution	Lotus Root Powder Solution
Weight (g)	50.03	50.05
Boiling water (mL)	250	250
Cool the solution for 1 h before the experiment.		

3.3.5. Solution Proportioning for Experimental Design—Qualitative Methods for Studying Absorption Balls

For the absorption ball, we designed two sets of distinct solutions to validate the absorption capacity of the ball, as shown in Figure 10 and Table 4, which are utilized for the qualitative investigation of the absorption ball.

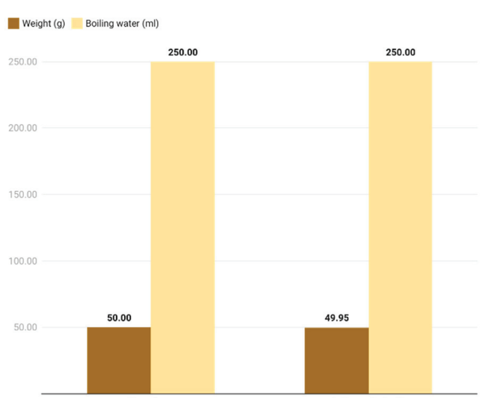

Figure 10. The experimental procedures were carried out utilizing a maize paste solution with high viscosity and a lotus root powder solution.

Table 4. Experimental Solution Proportioning in Qualitative Analysis.

Material Weight/Material Classification	Maize Flour	Lotus Root Starch
Weight (g)	50.00	49.95
Boiling water (mL)	250	250
Cool the solution for 1 h before the experiment.		

3.4. Experimental Procedure

3.4.1. Specific Steps for Starch Solution Experiments

- Preparation of Three Different Concentrations of Solutions

Three different weights of maize starch material, namely, 80 g, 120 g, and 160 g, were taken out and placed in transparent plastic bottles. Then, 100 mL of water was added to each bottle and stirred with the material until completely dissolved.

- Labeling of Eight Maize Kernels

Each maize kernel was labeled to effectively record any changes before and after the experiment and avoid deviation in the experimental data.

- Weighing and Recording of Each Maize Kernel

The weight of each maize kernel was recorded after labeling to ensure experimental rigor.

- Adding Maize Kernels to the Solution

The maize kernels were added to the experimental solution in preparation for the experiment.

- Starting the Stirring Experiment

The plastic bottle was placed on the support structure, and the motor was turned on to start the rotating and stirring experiment.

- Recording of Experimental Process

The entire process of the rotating and stirring experiment was recorded using a cellphone camera to avoid interference from other factors.

- End of Experiment and Removal of Maize Kernels

The power and motor were turned off at the end of the experiment, and the plastic bottle was removed from the support structure. The cap was opened and the maize kernels were taken out.

- Weighing and Recording of Each Maize Kernel

The removed maize kernels were placed on an electronic scale, and the weight of each kernel was recorded.

- Comparison of Weight Changes and Calculation of Average and Absorption Multiplicity

The average weight of each maize kernel before and after the experiment was calculated, and the relationship between the two multiplicities was determined.

3.4.2. Specific Steps for Multiple Solution Experiments

- Preparation of Four Different Solutions

The appropriate amount of the four materials was taken and placed in a weighed plastic cup. Then, 250 mL of boiling water was added to the materials, and the mixture was stirred until dissolved. The lid was sealed and the solution was left for 5 min. The concentration of the solution particles was observed, and more materials were added until the concentration was similar in all four solutions.

- Labeling of Six Maize Kernels

Each maize kernel was labeled to effectively record any changes before and after the experiment and avoid deviation in the experimental data.

- Remaining Experimental Steps were Consistent with the Above.

3.4.3. Specific Steps for Viscous Solution Experiments

- Preparation of Two Different Solutions

Firstly, 50 g each of maize paste powder and lotus root powder materials were taken, placed in a weighed plastic cup, and mixed with 250 mL of boiling water. The mixture was stirred until completely dissolved, and the lid was sealed and left for 5 min.

- Cooling and Weighing of Two Solutions for One Hour

The plastic bottle containing the two solutions was uncapped and allowed to cool for 1 h to simulate the relatively dry state of liquid food in the human body.

- Weighing and Recording of Six Maize Kernels

The weight of each maize kernel after labeling was recorded to ensure experimental rigor.

- Remaining Experimental Steps were Consistent with the Above.

3.5. Statistical Analysis

During experimental analysis, the arithmetic mean was utilized for statistical analysis. When calculating the mean from relative or average numbers, the key issue is the accurate selection of weights. The arithmetic mean is one of the most fundamental and widely used averages in statistics. It is an important indicator of the overall level and typical characteristics of a phenomenon. It abstracts away the specific differences in the quantity of the phenomenon, reflects the concentrated trend of the phenomenon, and is a representative value [75].

4. Discussion

In this section, we analyze the feasibility of C2C theory in product conceptual design based on the results of qualitative and quantitative experiments. The variations in the absorption capacity of maize seed in the three sets of starch solution experiments are illustrated in Figures 11–13. In the three groups of starch solutions, the performance of maize seed in terms of absorption values is depicted in Figures 14–16. Likewise, we have provided an overview of the results and offered suggestions. Two conceptual design schemes based on C2C theory are compared in more detail in this article and illustrated through experimental results. Finally, we summarize the impact of qualitative and quantitative experiments on demonstrating the influence of C2C theory in product conceptual design through a comparison of experimental data.

4.1. Qualitative and Quantitative Analysis of Hollow Maize Seed Experimental Results

In the evaluation methods of conceptual design, various methods have been proposed, including TOPSIS [76], the weighted product method (WPM) [77], multiple attribute utility theory (MAUT) [78], and the elimination method, among others. Based on the weighted product method, which analyzes the relative weights among interacting objectives, the most competitive design can be obtained. Therefore, in this study, hollow maize seeds were chosen as the experimental object and a series of analyses were conducted based on the weight data changes through before-and-after comparisons. The experiment was divided into quantitative analysis and qualitative analysis, where the former included a starch solution experiment and the latter included multiple solution experiments and viscous solution experiments using different materials to prepare solutions of similar concentrations. The qualitative analysis experiments used the same materials, but the viscosity of the prepared solutions was different.

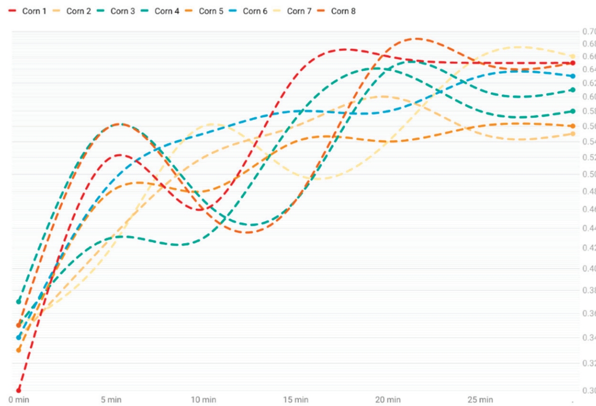

Figure 11. The weight changes of eight hollow dry maize seeds absorbing food in 100 mL/80 g starch solution at different times of the quantitative experiment.

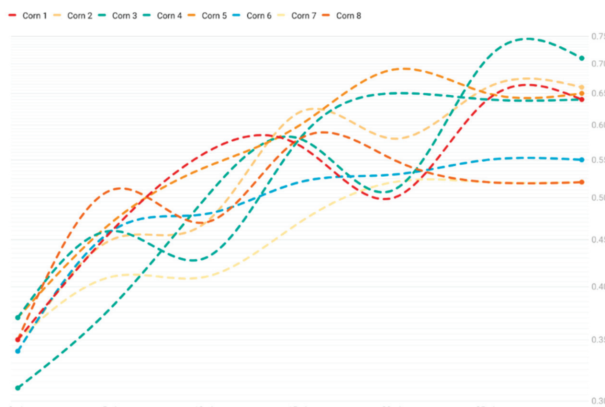

Figure 12. The weight changes of eight hollow dry maize seeds absorbing food in 100 mL/120 g starch solution at different times of the quantitative experiment.

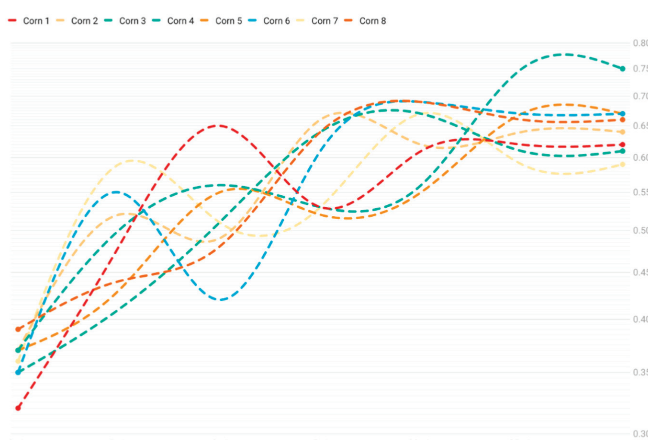

Figure 13. The weight changes of eight hollow dry maize seeds absorbing food in 100 mL/160 g starch solution at different times of the quantitative experiment.

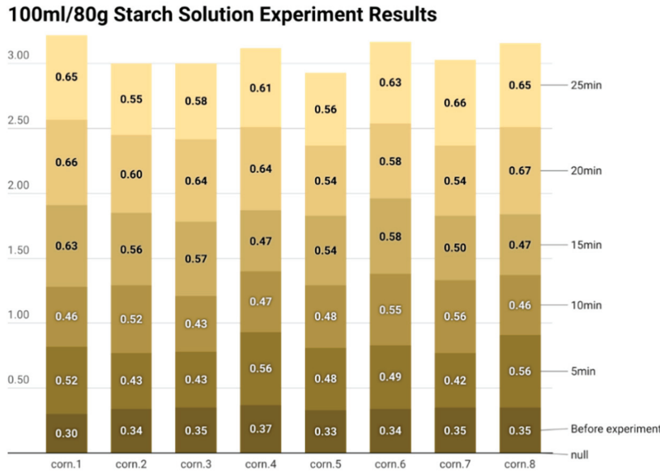

Figure 14. The absorption data of each maize seed in the starch solution in Experiment 1.

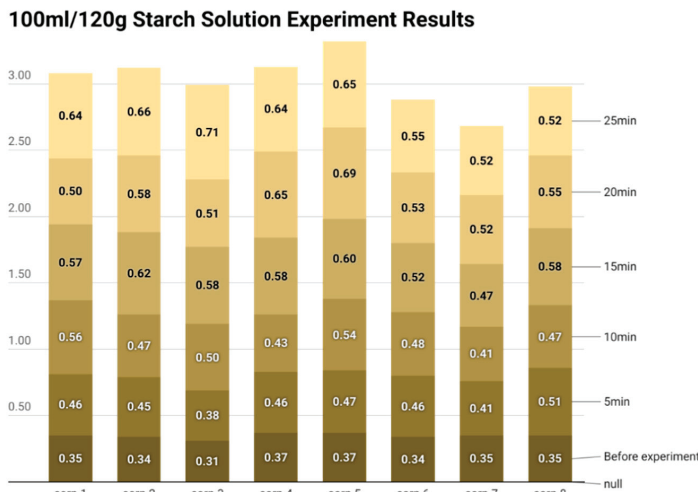

Figure 15. The absorption data of each maize seed in the starch solution in Experiment 2.

The purpose of the quantitative analysis experiment was to verify the absorption capacity of hollow maize seeds for different concentrations of solutions prepared with the same material. The purpose of the qualitative analysis experiment was to verify the absorption capacity of hollow maize seeds for solutions of similar concentrations prepared with different materials. Among the qualitative analysis experiments, the multiple solution experiment and the viscous solution experiment used the same materials, but the viscosity of the prepared solutions was different.

Overall, the weighted product method was used to analyze the relative weights of interacting objectives and obtain the most competitive design. The experimental results were based on a series of analyses of weight data changes and included quantitative and qualitative analysis experiments, such as the starch solution experiment, and multiple solution and viscous solution experiments.

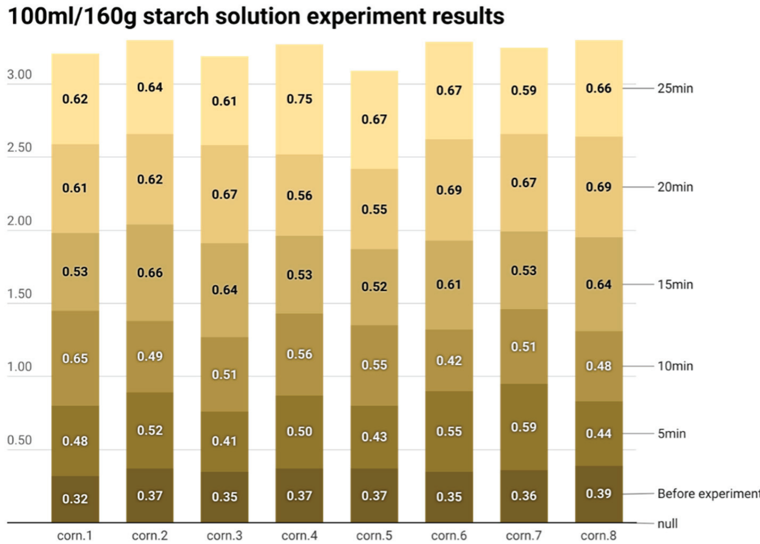

Figure 16. The absorption data of each maize seed in the starch solution in Experiment 3.

4.1.1. Experiment Quantitative Analysis Experiment—Starch Solution Experiment

- Experiment 1

In this experiment, hollow maize seeds were used, and each seed was washed several times with water before the experiment to reduce its weight as much as possible. Then, 80 g of starch was weighed and placed in a transparent plastic bottle. Following this, 100 mL of water was added to the bottle using a measuring cup, and the two were mixed thoroughly before the experiment started. The weight of the hollow maize seeds was recorded over time during the experiment, as shown in Tables 5 and 6. The experimental results are shown in Figures 11 and 14.

Table 5. Starch Solution Experiment 1 data results.

Starch Solution			After the Experiment (g)				
100 mL/80 g	Before Experiment (g)	Mean Value (g)	5 min	10 min	15 min	20 min	25 min
Maize Seed 1	0.30	0.34	0.52	0.46	0.63	0.66	0.65
Maize Seed 2	0.34		0.43	0.52	0.56	0.60	0.55
Maize Seed 3	0.35		0.43	0.43	0.57	0.64	0.58
Maize Seed 4	0.37		0.56	0.47	0.47	0.64	0.61
Maize Seed 5	0.33		0.48	0.48	0.54	0.54	0.56
Maize Seed 6	0.34		0.49	0.55	0.58	0.58	0.63
Maize Seed 7	0.35		0.42	0.56	0.50	0.54	0.66
Maize Seed 8	0.35		0.56	0.46	0.47	0.67	0.65

- Experiment 2

In this experiment, hollow maize seeds were used, and each seed was washed several times with water before the experiment to reduce its weight as much as possible. Then, 120 g of starch was weighed and placed in a transparent plastic bottle. Following this, 100 mL of water was added to the bottle using a measuring cup, and the two were mixed thoroughly before the experiment started. The weight of the hollow maize seeds was recorded over time during the experiment, as shown in Tables 7 and 8. The experimental results are shown in Figures 12 and 15.

Table 6. The average absorption rate and absorption rate of maize seeds in the starch solution at each time period were recorded in Experiment 1.

Mean/Absorption Rate			After the Experiment (g)				
100 mL/80 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.30	0.34	Mean value (g)				
Maize Seed 2	0.34		0.49	0.49	0.54	0.61	0.61
Maize Seed 3	0.35						
Maize Seed 4	0.37						
Maize Seed 5	0.33		Absorption rate				
Maize Seed 6	0.34		44%	44%	59%	79%	79%
Maize Seed 7	0.35						
Maize Seed 8	0.35						

Table 7. Starch Solution Experiment 2 data results.

Starch Solution			After the Experiment (g)				
100 mL/120 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.35	0.35	0.46	0.56	0.57	0.50	0.64
Maize Seed 2	0.34		0.45	0.47	0.62	0.58	0.66
Maize Seed 3	0.31		0.38	0.50	0.58	0.51	0.71
Maize Seed 4	0.37		0.46	0.43	0.58	0.65	0.64
Maize Seed 5	0.37		0.47	0.54	0.60	0.69	0.65
Maize Seed 6	0.34		0.46	0.48	0.52	0.53	0.55
Maize Seed 7	0.35		0.41	0.41	0.47	0.52	0.52
Maize Seed 8	0.35		0.51	0.47	0.58	0.55	0.52

Table 8. The average absorption rate and absorption rate of maize seeds in the starch solution at each time period were recorded in Experiment 2.

Mean/Absorption Rate			After the Experiment (g)				
100 mL/120 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.35	0.35	Mean value (g)				
Maize Seed 2	0.34		0.45	0.48	0.57	0.57	0.61
Maize Seed 3	0.31						
Maize Seed 4	0.37						
Maize Seed 5	0.37		Absorption rate				
Maize Seed 6	0.34		29%	37%	63%	63%	74%
Maize Seed 7	0.35						
Maize Seed 8	0.35						

- Experiment 3

In this experiment, hollow maize seeds were used, and each seed was washed several times with water before the experiment to reduce its weight as much as possible. Then, 160 g of starch was weighed and placed in a transparent plastic bottle. Following this, 100 mL of water was added to the bottle using a measuring cup, and the two were mixed thoroughly before the experiment started. The weight of the hollow maize seeds was recorded over time during the experiment, as shown in Tables 9 and 10. The experimental results are shown in Figures 13 and 16.

Table 9. Starch Solution Experiment 3 data results.

Starch Solution			**After the Experiment (g)**				
100 mL/160 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.32	0.36	0.48	0.65	0.53	0.61	0.62
Maize Seed 2	0.37		0.52	0.49	0.66	0.62	0.64
Maize Seed 3	0.35		0.41	0.51	0.64	0.67	0.61
Maize Seed 4	0.37		0.50	0.56	0.53	0.56	0.75
Maize Seed 5	0.37		0.43	0.55	0.52	0.55	0.67
Maize Seed 6	0.35		0.55	0.42	0.61	0.69	0.67
Maize Seed 7	0.36		0.59	0.51	0.53	0.67	0.59
Maize Seed 8	0.39		0.44	0.48	0.64	0.69	0.66

Table 10. The average absorption rate and absorption rate of maize seeds in the starch solution at each time period were recorded in Experiment 3.

Mean/Absorption Rate			**After the Experiment (g)**				
100 mL/160 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.32	0.36	Mean value (g)				
Maize Seed 2	0.37		0.49	0.48	0.49	0.57	0.49
Maize Seed 3	0.35						
Maize Seed 4	0.37						
Maize Seed 5	0.37		Absorption rate				
Maize Seed 6	0.35		36%	33%	36%	58%	36%
Maize Seed 7	0.36						
Maize Seed 8	0.39						

Using the starch solution experiment as a case study, a quantitative analytical method was employed to design an experiment and verify the absorption capacity of hollow desiccated maize kernels. The findings demonstrated that the hollow desiccated maize kernels exhibited notable absorption capacity for the same ingredient at varying concentrations. Moreover, with an increase in the experimental duration, the absorption rate of the hollow desiccated maize kernels gradually increased, ultimately reaching a steady state.

The results of the experiment indicated that hollow desiccated maize kernels possess a fundamental capacity to absorb everyday food. As time progresses, the absorption ability of the kernels increases, eventually reaching a plateau.

4.1.2. Qualitative Analysis Experiment—Multiple Solutions Experiment

- Experimental investigation of black sesame paste solution

In this experiment, hollow desiccated maize kernels were used, and each kernel was washed multiple times before the experiment to minimize its weight.

Firstly, 65.02 g of black sesame paste powder was weighed and placed in a transparent plastic bottle. Then, 250 mL of boiling water was added to the bottle using a measuring cup, and the two were mixed thoroughly and allowed to stand for 5 min. The hollow desiccated maize kernels were then placed into the bottle, and the experiment was started. The experimental results are shown in Table 11.

- Experimental investigation of maize paste solution

Firstly, 60.23 g of maize paste powder was weighed, and 250 mL of boiling water was added using a graduated cylinder. The two components were thoroughly mixed and allowed to stand for 5 min. The hollow desiccated maize kernels were then added to the mixture, and the experiment was initiated. The experimental outcomes are presented in Table 12.

Table 11. Experimental Data of Black Sesame Paste Solution.

Black Sesame Aleurone / Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize 1	0.27	0.34	-	0.50	0.57	68%
Maize 2	0.34			0.58		
Maize 3	0.32			0.50		
Maize 4	0.35			0.53		
Maize 5	0.37			0.68		
Maize 6	0.36			0.65		

Table 12. Experimental Data of Maize Paste Solution.

Maize Paste / Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.26	0.34	-	0.56	0.64	88%
Maize Seed 2	0.36			0.66		
Maize Seed 3	0.32			0.62		
Maize Seed 4	0.34			0.71		
Maize Seed 5	0.37			0.61		
Maize Seed 6	0.36			0.65		

- Experimental investigation of lotus root powder solution

Before the experiment, each maize kernel was washed multiple times to remove any residues inside and minimize the weight of the dry maize kernels. Then, 60.55 g of lotus root powder was weighed, and 250 mL of boiling water was added using a measuring cup. The two were mixed thoroughly and allowed to stand for 5 min. The experimental results are shown in Table 13.

Table 13. Experimental Data of Lotus Root Starch Solution.

Lotus Root Powder / Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.27	0.33	-	0.59	0.63	91%
Maize Seed 2	0.35			0.62		
Maize Seed 3	0.32			0.59		
Maize Seed 4	0.34			0.65		
Maize Seed 5	0.36			0.65		
Maize Seed 6	0.36			0.65		

- Experimental investigation of brown rice flour solution

Before the experiment, the cleaning steps of the previous experiment were repeated. Then, 100.58 g of brown rice flour was weighed, and 250 mL of boiling water was added using a measuring cup. The two were mixed thoroughly and allowed to stand for 5 min. The experimental results are shown in Table 14.

Table 14. Experimental Data of Brown Rice Flour Solution.

Maize Flour Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.28	0.34	-	0.48	0.52	53%
Maize Seed 2	0.36			0.47		
Maize Seed 3	0.31			0.45		
Maize Seed 4	0.35			0.71		
Maize Seed 5	0.37			0.51		
Maize Seed 6	0.36			0.50		

During the qualitative study, we conducted experiments using four different solutions to explore the absorption capacity of corn seeds for various foods, with the results illustrated in Figure 17. Despite the variation in the proportions of the four materials, the phenomenon observed in Figure 18 still occurred in the comparison of solution concentrations.

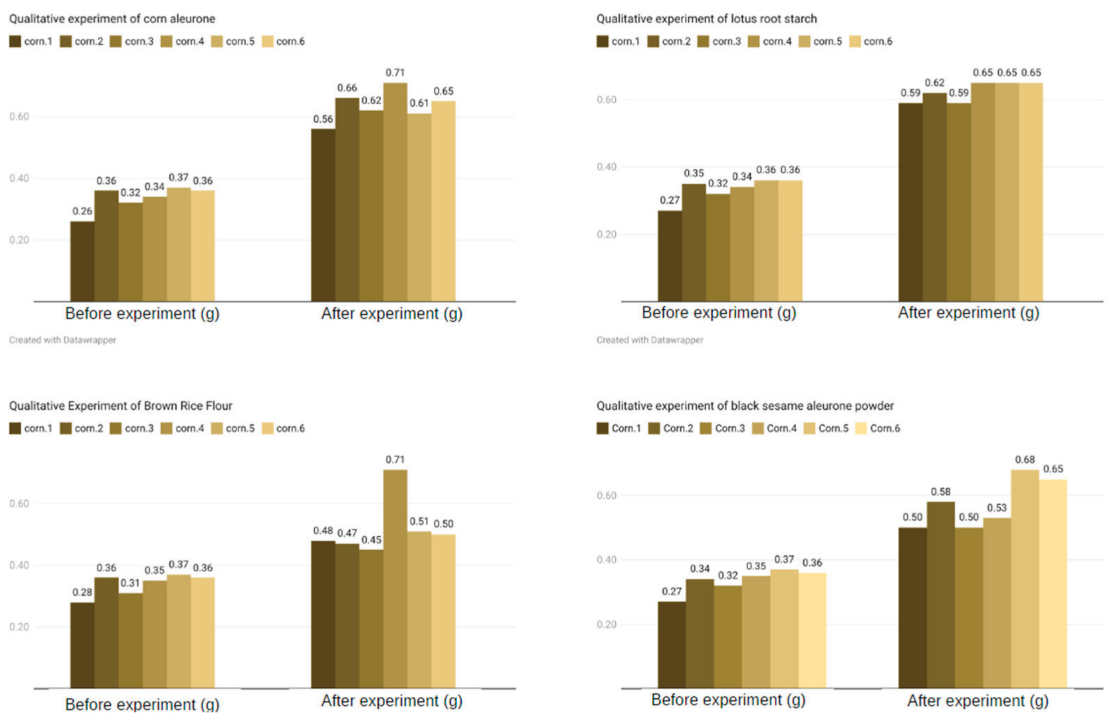

Figure 17. In the qualitative experiment, the absorption capacity of hollow maize seed was tested by four different solutions, aiming to investigate the absorption ability of the conceptual product in various solutions.

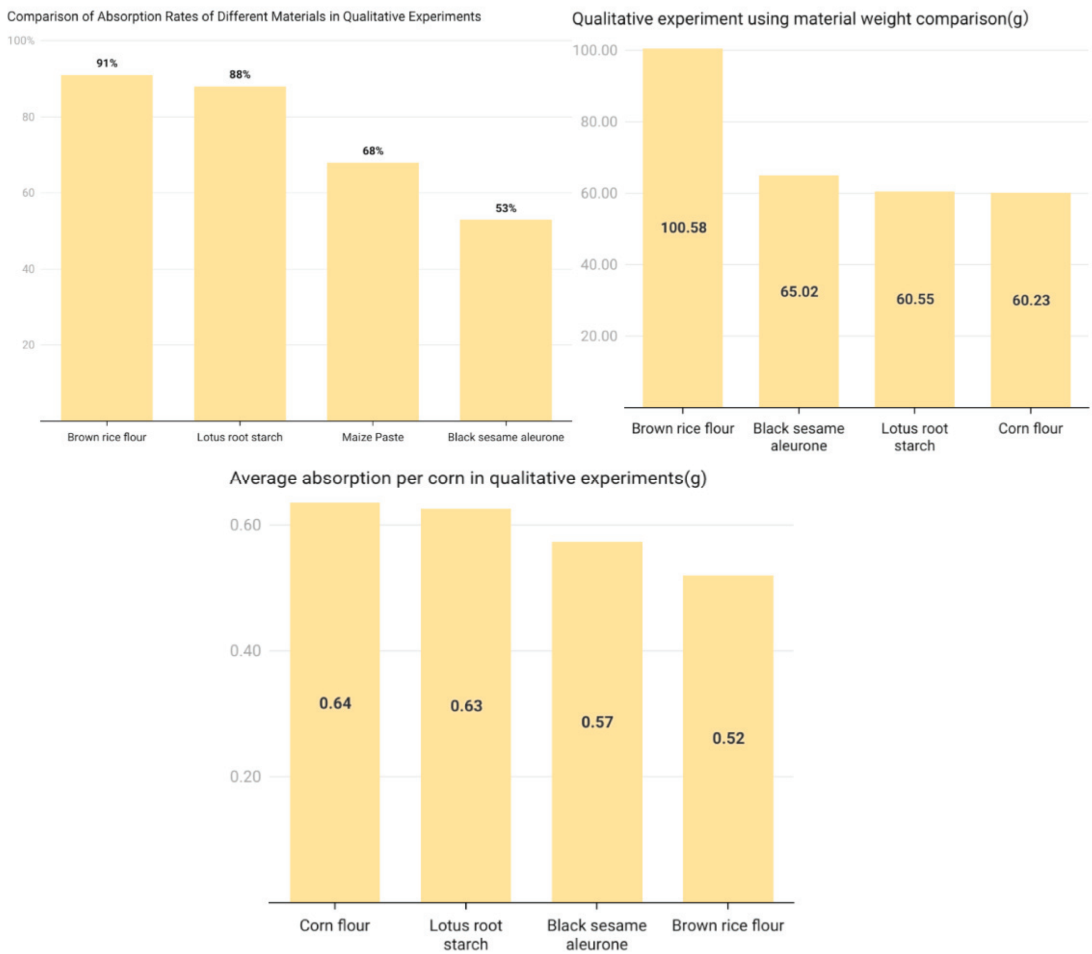

Figure 18. In the qualitative experiment, a comparison was made of the four different qualitative experimental data, and a summary was made of the material weight used in the experimental solutions, the average absorption of the conceptual product in different solutions, and the absorption rate in different solutions.

In the experiment, four distinct solutions were utilized to simulate various food sources in human dietary practices. The results of the qualitative experiment are presented in Table 15. The results of the experiment affirmed that hollow desiccated maize kernels have the capability to absorb diverse food sources and that the absorption rate is concentration dependent. Furthermore, the experiment demonstrated that the absorption rate of hollow maize kernels is positively correlated with the viscosity of the solution. This study provides empirical evidence for the potential use of hollow desiccated maize kernels as a food absorbent in a variety of applications. The outcomes of this research may facilitate the advancement of novel food technologies and formulations in the future.

Table 15. Summary of Qualitative Experiment Results.

Summary of four aspects of qualitative experimental research
Used material weight (g):
Brown rice flour (100.58) > Black sesame aleurone (65.02) > Lotus root flour (60.55) > Maize paste (60.23)
Solution viscosity:
Maize paste solution > Lotus root flour solution > Black sesame paste solution > Brown rice flour solution
Average absorption (g):
Maize paste solution (0.64) > Lotus root starch solution (0.63) > Black sesame paste solution (0.57) > Brown rice flour solution (0.52)
Absorption rate:
Maize paste solution (91%) > Lotus root starch solution (88%) > Black sesame paste solution (68%) > Brown rice flour solution (53%)

4.1.3. Qualitative Analysis Experiment—Viscous Solution Experiment

- Experiment of viscous maize paste solution

The previous experiment has confirmed that the absorption rate of dried maize kernels is higher in solutions with higher viscosity. In this round of experiments, the absorption capacity of dried maize kernels in solutions with higher viscosity will be further investigated by extending the experimental duration.

Before the experiment, the maize kernels were washed and dried. Then, 50.03 g of maize paste powder was weighed, and 250 mL of boiling water was measured using a graduated cylinder. The two were thoroughly mixed and allowed to cool for 60 min to increase the viscosity of the solution.

The increased viscosity of the solution was achieved by allowing it to cool and settle, which is expected to enhance the absorption ability of dried maize kernels, The results are shown in Table 16.

Table 16. Experimental Data of Viscous Maize Paste Solution.

Viscous Maize Paste Solution / Experimental Subjects	Before Experiment (g)	Mean Value (g)	25 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.28	0.35	-	0.56	0.64	83%
Maize Seed 2	0.37			0.70		
Maize Seed 3	0.34			0.53		
Maize Seed 4	0.37			0.64		
Maize Seed 5	0.38			0.72		
Maize Seed 6	0.38			0.67		

- Experiment of Viscous Lotus Root Starch Solution

Prior steps to the experiment were carried out as in the previous trial. Specifically, 50.05 g of lotus root powder was weighed and mixed thoroughly with 250 mL of boiling water, as measured by a volumetric flask. The resulting mixture was left to cool for 60 min, during which time the solution's viscosity increased due to its settling. This procedure was performed to achieve a higher level of homogeneity in the solution and to ensure that the experiment was carried out under standardized conditions, The experimental results are shown in Table 17.

Table 17. Experimental Data of Viscous Lotus Root Starch Solution.

Viscous Lotus Root Starch Solution / Experimental Subjects	Before Experiment (g)	Mean Value (g)	25 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.27	0.34	-	0.59	0.63	85%
Maize Seed 2	0.36			0.69		
Maize Seed 3	0.31			0.52		
Maize Seed 4	0.36			0.67		
Maize Seed 5	0.37			0.62		
Maize Seed 6	0.37			0.71		

In contrast to previous experiments, the current study on viscous solutions required an adjustment of the experimental time to 25 min corresponding to the extended retention time of solid foods during human digestion.

- Conclusions:

The results of the second experiment showed that hollow dried maize kernels had a noteworthy ability to absorb high viscosity solutions approximately equal to their own weight.

4.1.4. Derivative Concept Product Absorption Experiment

The experiment employed a small ball derivative structure that was designed based on dry maize kernels, with a total of four balls. Subsequent analysis was conducted by comparing the weight before and after the experiment. Two types of food were used for the experiment under the same conditions as the previous round, with the aim of verifying whether the ball derivative structure could increase its self-absorption rate while ensuring that the absorbed food does not flow out. The goal was to investigate the effectiveness of the ball derivative structure in enhancing its self-absorption ability.

- Experiment of viscous maize paste solution

Before the experiment, four small balls were labeled with serial numbers and weighed individually for subsequent weight comparison. Then, 50.00 g of maize starch was weighed, and 250 mL of boiling water was measured with a measuring cup. The two were thoroughly mixed and allowed to cool for 60 min, The experimental results are shown in Table 18.

Table 18. Experimental Data of Viscous Maize Paste Solution.

Viscous Maize Paste Solution / Experimental Subjects	Before Experiment (g)	Mean Value (g)	25 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Ball 1	1.20	1.19	-	5.65	5.34	349%
Ball 2	1.18			5.22		
Ball 3	1.21			4.93		
Ball 4	1.15			5.54		

- Experiment of viscous lotus root starch solution

The pre-experimental procedures were identical to the previous experiment. Then, 49.95 g of lotus root powder was weighed, and 250 mL of boiling water was measured using a graduated cylinder. The two were thoroughly mixed and allowed to cool for 60 min, The experimental results are shown in Table 19 and Figure 19.

Table 19. Experimental Data of Viscous Lotus Root Starch Solution.

Viscous Lotus Root Starch Solution / Experimental Subjects	Before Experiment (g)	Mean Value (g)	25 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Ball 1	1.21	1.19	-	2.84	3.15	165%
Ball 2	1.18			2.71		
Ball 3	1.21			3.72		
Ball 4	1.15			3.33		

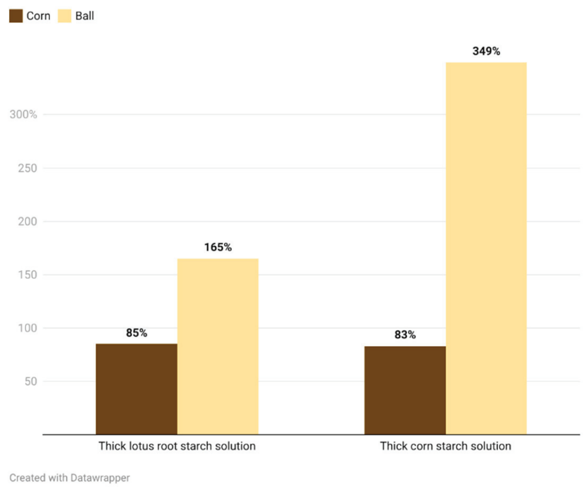

Figure 19. A comparison was made between the absorption rates of the derivative small balls of the conceptual product and the hollow dry maize kernels of the conceptual product in viscous lotus root powder solution and viscous maize starch solution.

- Conclusions:

This round of experiments confirmed the absorptive ability of the small ball derivative structure that was designed based on maize kernels. Under conditions identical to the previous experiment, the absorptive rate of the small ball derivative structure was significantly improved.

4.2. Analysis of Experimental Results

In this study, a series of experiments were conducted to investigate the absorbency of hollow maize seeds under different conditions.

1. Firstly, the absorbency of the same material at different concentrations on hollow maize seeds was quantitatively studied.
2. Secondly, the absorbency of four different solutions on hollow maize seeds was qualitatively studied.
3. Thirdly, the absorbency of two high-viscosity solutions on hollow maize seeds was qualitatively studied.
4. Finally, the absorbency of two high-viscosity solutions on small ball derivatives based on hollow maize seeds was qualitatively studied.

The starch solution experiment confirmed that hollow maize seeds have absorbency, and the absorbed weight increases over time and eventually stabilizes.

The multi-solution experiment showed that hollow maize seeds can absorb solutions of different viscosities. In addition, the experimental conclusion is that the absorbency of hollow maize seeds in low-viscosity solutions increases with the increase of solution concentration.

The viscous solution experiment confirmed the absorbency of hollow maize seeds to high-concentration viscous solutions. These experiments collectively demonstrate the ability of hollow maize seeds to absorb solutions in different states.

Theoretically, multiple solutions can be likened to different types of food consumed by humans, while the stirred experimental environment can be likened to the human digestive process. Therefore, hollow maize seeds may produce similar effects in the human body.

The structural derivative experiment confirmed that small ball derivatives based on hollow maize seeds have absorbency. Moreover, the experiment indicated that the absorbency rate of the small balls was higher than that of the hollow maize seeds.

In conclusion, our study provides comprehensive evidence for the absorbent properties of hollow maize seeds under various conditions, including different types of solutions and concentrations. The results of this study could have potential implications for various fields, which can reference areas like food processing and diet control.

Furthermore, a comparison of the viscous solution experiments and the derivative structure experiments is presented in Table 20.

Table 20. Comparison of Absorption Rate of Different Products in Viscous solution.

Comparison of the Two Concept Products			
Viscous Maize Paste Solution		**Viscous Lotus Root Starch Solution**	
Experimental subjects/Absorption rate			
Maize Seed	**Ball**	**Maize Seed**	**Ball**
83%	349%	85%	165%

According to Table 20, the experimental results of the derivative structure demonstrate that the design of the small ball prototype has effectively improved the absorption rate compared to the hollow maize seed, further proving the rationality of the small ball derivative structure.

4.3. Discussion

In this investigation, we not only adhered to the three fundamental principles of C2C theory in our conceptual design, but also thoroughly integrated these principles—waste as a resource, utilization of renewable energy, and respect for diversity—into the structure of both quantitative and qualitative experimental setups.

In the quantitative experiments, we selected varying concentrations of starch solutions, examining their absorption by our concept product. This approach aimed to evaluate the design's capacity to absorb different concentrations of a single food type. Starch, a renewable natural resource, aligns with the C2C principle of utilizing renewable energy sources. Its circulation within the ecosystem resembles that of biological nutrients, emphasizing the waste-as-resource principle. In the qualitative experiments, we designed multiple solutions to assess the product's absorption capabilities, simulating a diverse array of foods consumed in daily life to approximate real-world eating environments. The experimental design of both the qualitative and quantitative studies align with the C2C principle of celebrating diversity.

In summary, the design of these experiments not only verifies the feasibility of the concept product but also reflects the core tenets of C2C theory. By incorporating the three principles of C2C theory into our experimental design, we seek to ensure that the concept product fulfills its intended function while adhering to the standards of environmental protection and sustainable development.

Furthermore, in the practical component of our research, we designed a concept product to evaluate its weight-loss properties. This aspect of the study may overlap with certain medical clinical investigations, which we acknowledge. Our study primarily focuses on evaluating the conceptual design of a product guided by C2C theory, and the practical research emphasizes assessing the feasibility of the conceptual design through theoretical investigations. It is important to note that this study addresses only a portion of the weight-loss process through product conceptual design within a laboratory setting. There remain numerous specialized issues in the medical field that we are currently unable to address, which is a limitation of our research.

In future studies, we plan to actively collaborate with researchers in the medical field to obtain relevant research qualifications and subsequently concentrate on addressing specialized issues in the realm of weight loss. This interdisciplinary approach will ensure a more comprehensive understanding of the concept product's potential in real-world applications and its overall impact on health and well-being. By integrating insights from multiple fields, we aim to create a product that not only adheres to the principles of C2C design but also addresses the complex challenges associated with weight loss and human health. Future studies may contemplate adopting diverse approaches such as integrating control groups, repositioning experimental materials, or deploying live animal experiments to better reflect qualitative and quantitative experimental environments under real-world conditions.

5. Conclusions

This paper elucidates the practicability of applying Cradle to Cradle (C2C) theory in conceptual product design and also evaluates the efficacy of amalgamating theory and practice in sustainable conceptual design. This study exemplifies how natural and renewable resources can be innovatively utilized to engender novel products with specific functional attributes, which is congruent with the tenets of sustainable concept design, accentuating the use of eco-friendly materials and efficacious production processes that abate waste and environmental impact.

Qualitative and quantitative experiments were implemented to ascertain the viability of the concept product by scrutinizing the absorption properties of hollow corn seeds. As evidenced by our experiments, the capacity of hollow corn seeds to assimilate disparate types and concentrations of solutions intimates that these seeds can be exploited as a natural and renewable resource that can be utilized for a diverse range of applications. For instance, the absorption properties of hollow maize seeds could be employed to fashion novel food products or constituents with specific functional properties, such as augmentation of texture or improved nutrient assimilation.

Altogether, this study furnishes a comprehensive inquiry into the absorption properties of hollow maize seeds under sundry conditions, which can proffer a constructive impact on the evolution of derivative product designs. Moreover, experiments on the derivative concept corroborated the extension of our theoretical practice. The outcomes of this study make a salutary contribution to the advancement of derivative product design, elucidating how C2C theory can be harnessed to fabricate innovative products that are both functional and sustainable. This study lays the groundwork for future research as it underscores the significance of considering the sustainability of product development at the conceptual stage. By assimilating the tenets of sustainable conceptual design, designers and manufacturers can engender products that meet consumer needs while safeguarding the environment and conserving natural resources. These findings also underscore the importance of introducing C2C theory at the concept stage in research on product development. Although C2C theory has a broader application in terms of landing products or supporting decision making, it still plays a pivotal role in ameliorating the product design ecosystem as a methodology for refining product concepts.

Notwithstanding, we concede the constraints of our methodology. Firstly, our study was conducted in a laboratory setting, instead of an actual production line or product use environment. While this facilitates control over other factors that may affect qualitative and quantitative experiments, it may not precisely emulate the scenarios and equipment conditions of qualitative and quantitative experiments in the industry. Secondly, we acknowledge the limitations regarding the analysis of energy consumption for the product. Throughout the C2C cycle, energy dynamics play a crucial role, with different states of the product form and manufacturing methods and processes leading to varying levels of energy consumption. While energy loss is not explicitly emphasized as a key principle of C2C theory, it does advocate for reduced energy loss throughout the overall cycle, which our research also recognizes. Consequently, our study's focus on the conceptual design of the product based on C2C theory and the evaluation process utilizing qualitative and quantitative experiments has inherent limitations in addressing energy consumption and cycles.

Given the constraints of the laboratory environment, our study has limited capabilities in evaluating energy consumption and cycles throughout the concept product's life. This challenge parallels the development of concept vehicles, where the steps required to progress from proof of concept to mass production involve substantial cost and energy optimizations.

Similarly, our research faces the same challenges. In our subsequent research, we will continue to strengthen the analysis of energy consumption across various aspects of product forms guided by C2C theory, in order to enhance the practical implementation of the C2C approach. By addressing the limitations of energy consumption and cycle evaluation, we aim to ensure that our research adheres to the principles of environmental sustainability and contributes to the advancement of C2C theory in real-world applications.

Moreover, the integration of emerging technologies such as artificial intelligence (AI) represents a promising avenue for advancing sustainable design theory and its intersection with technological factors. For instance, AI technology can provide a high-quality simulation environment for sustainable design and even product design based on C2C theory. By leveraging digital simulation technology and cutting-edge innovations, researchers can bridge the gap between the conceptual design stage and the product development phase. This approach enables more effective evaluation of sustainable design's efficacy and applicability, offering additional development paths for real-world product development and allowing sustainable design to thrive in diverse contexts.

Our research explores the research approach of inferring design possibilities from the perspective of sustainable design, based on the assumption of the referred sustainable materials that are safe, harmless, while sharing required physical characters. Obviously, the contribution of this study lies in exploring the effectiveness of a sustainable design method rather than explicitly guidance in clinical medicine or healthcare. We believe that research at this stage should not be used as a basis or guidance for medical or healthcare production and rehabilitation without strict clinical trials with rigorous health and safety permits.

In conclusion, while our current study has its limitations, future research will explore more comprehensive approaches, incorporating advanced technologies and more extensive energy consumption analyses, to ensure that C2C theory can be successfully applied to practical, sustainable product development.

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sustainability

Article

Research-by-Design in Complex Systems: Reflections on Approaches Used to Reimagine Environmentally Sustainable, High-Welfare Poultry Housing Futures

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Abstract: Despite projected global rises in chicken consumption, growing environmental and welfare challenges threaten the future of commercial poultry production. Though some of these challenges, such as biosecurity, sourcing, pollution, and waste, have been thoroughly researched, the open-ended, complex, and interrelated nature of the sector means that it is difficult for poultry producers to know how to change. Design may offer a new way to analyse and reframe these challenges, to speculate on a range of different solutions for these complex systems of production. This paper reflects on the research-by-design methods applied to reimagine environmentally sustainable, high-welfare poultry housing futures. The paper is based on an eighteen-month long, multidisciplinary research project with a large U.K.-based poultry farming integrator, a poultry house ventilation and equipment supplier, and academic partners with expertise in research-by-design and bird welfare. After contextualising challenges faced by the poultry sector, the paper outlines a three-step, iterative approach within which design methods were applied, beginning with (1) a baseline analysis of farm inputs, outputs, actors, and networks, and then (2) a consolidation of themes and scenarios, leading to the development of (3) a compendium of ideas for the future of poultry farming. The Results section presents three design propositions, each imagining different futures by recreating the farm as a system of "closed-loop" flows, reframing the "chicken as client" and challenging current centralised models of production to connect consumers to food provenance and impact. These propositions function as vehicles to test design methods, such as designing for resource flows challenging actor hierarchies and hacking stakeholder networks. While some interesting ideas are presented, the paper highlights the complexity of the challenge and reflects on the value of design to reframe these challenges to collaboratively foster new perspectives and mindsets.

Keywords: research-by-design methods; design for environmental sustainability; high-welfare farming design; poultry housing futures; visualisation methods

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1. Introduction

By 2030, global meat production is projected to increase by 13%, while poultry production is set to rise by 17% in the same period [1]. Although the sector is relatively low carbon compared with other livestock sectors, poultry production significantly impacts water and air quality and contributes to global resource use and waste [2,3]. In the United Kingdom (U.K.), climate legislation, including net-zero targets, requires the poultry sector to fundamentally redress operations to reduce environmental impact and build resilience to the direct and indirect impacts of climate change. Consumers are also becoming more aware of bird welfare but are reluctant to pay more for their food [1]. As such, higher welfare products still represent a small portion of the chicken market. Poultry producers must balance these concerns along with biosecurity risks that are easier to manage through indoor housing environments. While these challenges have been explored extensively in a siloed way, their collective complexity means that it is difficult to consider how the sector might holistically adapt for the future [3]. This paper reflects on an 18-month long, applied, multidisciplinary project between the poultry sector in Northern Ireland (N.I.) and architectural design-researchers in academia to explore this question through research-by-design methods. As well as the design-research team, the project partners included Moy Park, a large U.K. (United Kingdom) poultry integrator, and JF McKenna, a poultry house ventilation and equipment supplier, and academic experts in poultry behaviour and welfare. The project was funded by Innovate UK to address and support innovation on net-zero and high-welfare agriculture through the design of future poultry housing. However, this paper is reframed towards environmental sustainability, including biosecurity, resource consumption, waste, and pollution issues.

After highlighting the challenges faced by the poultry sector and exploring typical poultry housing models, this paper reflects on the value of research-by-design methods to reimagine environmentally sustainable, high-welfare poultry house futures. It also reflects on how these methods facilitate new perspectives and mindsets within complex productive industries, in the agrifood sector and beyond. The benefit of undertaking this research in an academic setting, across an extended time-period, was in the distancing of focus from the day-to-day operations of the poultry integrator towards the exploration of long- and short-term opportunities that enable "more good" rather than attempting to simply make the poultry housing and systems "less bad". The design-research team developed an "Ideation Hourglass" framework to support top-down and bottom-up ideas, spanning different scales and timeframes to inform pathways to change. Under this framework, the team used a three-step approach to understand and reimagine poultry housing. Within each iterative, interconnected step, a range of established design tools were tested, and visualisations produced to capture, communicate, and critique ideas. The cross-disciplinary team met regularly to assess developed ideas and ideate new ones. The project culminated in the development of three propositional concepts for future poultry housing. While these propositions consolidated baseline analysis, themes, and potential scenarios developed to consider poultry sector futures, in this paper, they are used as vehicles to explore and reflect on the mix of design approaches to develop them and how these might inform ways to use design to unpack and reimagine other complex systems.

2. Background

2.1. Poultry Production Impacts and Challenges

Around 60 billion chickens are slaughtered globally per year [4]. Agriculture accounts for 14.5% of global anthropogenic greenhouse gas (GHG) emissions [5]. Poultry and egg production contributes to 8% of this figure, around 0.12% of total GHG emissions [5]. In June 2020, 1.15 billion chickens were slaughtered in the U.K., with a total production value of £2.25 billion [6]. In this context, agriculture accounts for 10% of annual greenhouse gas emissions (GHG) [7]. The poultry sector accounts for about 13% of the U.K.'s gross agricultural output and 2% of the agriculture sector's global warming potential [3]. Greenhouse gas emissions in the poultry sector are attributed to a range of operational sources. The global warming potential of standard poultry production systems in the U.K. are associated with feed and water (71.2%), electricity (3.7%), gas and oil (9.8%), housing and land (12.1%) and manure and bedding (3.2%) [3].

In its Sixth Carbon Budget, the Climate Change Committee recommended that the agricultural sector increase efficiencies in resource production, promote biodiversity, and facilitate greenhouse gas removals to address climate targets [8]. In 2022, Northern Ireland (N.I.) agreed on its first Climate Change Bill [9]. Like the UK, it seeks to meet net-zero carbon by 2050 [10]. Despite this, the challenge of making the poultry sector more environmentally sustainable is particularly acute in N.I. as agriculture is the only sector to have increased emissions since the 1990 baseline and livestock farming contributes significantly to the regional economy [11]. The poultry sector makes up 18.5% of N.I.'s gross agricultural output, 5.5% more than the U.K. [11]. Annual greenhouse gas emissions from agriculture accounts for 26% of total emissions, 16% more than the UK [12]. Part of this can be attributed to the rapid increase in the size of the poultry sector, particularly in poultry populations for meat consumption. Between 2016 and 2020, the poultry population in N.I. rose from 14.5 to 15.4 million [13].

The rapid development of this sector has created a complex supply chain and fostered the development of supporting industries, from poultry feed manufacturers to anaerobic digestors for poultry litter management. Furthermore, land spreading is currently one of the primary ways of managing litter from broiler houses, contributing significantly to a phosphorous (P) surplus in N.I. In 2017, the national P surplus was 12.3 kg P ha^{-1} [14]. Consequently, eutrophication of waterways is a prominent issue, detrimentally affecting the water quality of major rivers and lakes. In 2021, none of N.I.'s 450 river water bodies achieved good or high-level status, down from 24% in 2015, compared with 14% of English rivers rated good status [15,16]. These pressures have brought into sharp focus the environmental impact of the poultry sector and have opened questions around how best to decarbonise operations and reduce the impacts of sourcing and waste management.

Welfare is another concern for the poultry sector. Most consumers say that it is an important consideration when they purchase meat [17]. Despite this, products labelled as higher welfare, such as organic options, make up a small proportion of market share, reflecting that consumers do not want to spend more on high-welfare products. Commercial poultry producers must also balance bird welfare with biosecurity requirements, to mitigate against seasonal outbreaks of avian influenza (AI). A record number of cases of AI were confirmed in Great Britain (GB) in the winter of 2021/22 [18]. AI affects wild and commercial bird populations and presents a significant public health threat, and once detected on farms, farmers must cull tens of thousands of birds, impacting income as a result [19]. In large-scale poultry production, indoor housing is preferred, despite the impact on welfare [20]. The Better Chicken Commitment outlines ways to improve welfare in indoor-reared birds; by reducing stocking densities, careful breed selection and improved environmental standards, such as natural light, perching spaces, and good air quality [21].

2.2. Poultry House Typology

Historically, poultry houses were simple, lean-to timber structures capable of holding 10–12 birds. These free-range systems enabled the birds to roam extensively and required the farmer to move long distances to clean or supply feed and water to the houses. More intensive systems emerged, designed to hold hundreds, then thousands of birds at a time. These structures were timber framed, used natural ventilation, and integrated automated feed and drink lines. In recent years, conventional poultry houses have been designed as steel, portal frame structures with insulated façade panels and an uninsulated concrete floor.

Today, Moy Park's average house is approximately 20 m by 80 m and capable of holding 34,500 birds. Each house completes 6.8 cycles per year on average, so that around 234,600 birds occupy a house annually. Heating systems in Moy Park's estate use primarily biomass, with a small proportion using natural gas. As well as being artificially lit, manual opening strip windows with external shutters are installed along the length of the house to provide controlled natural light. The house is ventilated through side inlets and ridge extracts with artificial fan systems to aid air movement. This lightweight structure, with low thermal mass, is vulnerable to the increased occurrence of extreme hot and cold weather in the U.K. [22]. As a result, poultry houses rely heavily on mechanical systems to heat and move air. This is costly, wasteful, and can sometimes be insufficient at maintaining an optimum indoor environment during extreme weather events.

In recent years, notable examples of broiler and laying houses have emerged which aim to reduce operational energy use and improve bird welfare. These deviate from the conventional portal frame typology. The Rondeel is a circular laying house with alternate day and night segments and an outer edge for play and dustbathing [23]. Even though the cost of operating the Rondeel is greater than a typical house, the design significantly improves animal welfare because it hosts smaller flock sizes and creates variable environments to support a range of needs. The Windstreek Broiler House is another example of a new poultry housing typology [24,25]. Its 11-m-high roof avails of natural cross ventilation, while heated motherhoods reduce space heating to several occupied zones. This house has a large north-facing elevation, which results in a significant increase in natural light, with glazing equivalent to 50% of the floor area compared to 3% in conventional housing. These design strategies help to reduce operational energy of the house by 80% when compared to a conventional house. While both designs offer interesting insights into the future of the poultry house, their operation is predicated on designing architectural and management solutions without explicitly integrating novel, circular systems that balance environmental and welfare concerns.

3. Literature and Methods

Design-research uses abductive reasoning to define complex problems and generate solutions simultaneously and across iterations in what philosopher Karl Popper defines as conjecture and refutation [26]. This is reflected in IDEO's divergent–convergent creative design process [27]. While traditional research is mostly analytical, exploring "what is", research-by-design casts into the future to explore "what if" [28]. This approach, combined with systems thinking, which supports pattern-finding in complex environments, is useful in determining solutions for "wicked" problems, which are difficult to define, incomplete and interdependent [29].

In this research study, the design-research team implicitly referred to Schön's model of Reflective Practice, which defines three stages in a design cycle: frame, move and evaluate [30]. This is mirrored in the structure of this section of the paper, which defines three steps to reimagine and visualise environmentally sustainable, welfare-friendly poultry house futures using research-by-design methods. While there are three steps described, these approaches are iterative and non-linear, with interlinks across and between.

The first step in this research-by-design approach begins with a baseline analysis of Moy Park's existing poultry housing, networks, and operations. While this step is not necessarily design-led, it highlights challenges in which the team can develop design solutions. Keeffe and Cullen describe this step as defining content in which a formal space can be contained [31]. The second step comprises a compendium of themes and scenarios to explore the wider context in which the current and future poultry house exists. The second step straddles analysis and design, to inform "what-if" questions emerging from the research in steps one and two. The third step is design-led, exploring various holistic, thematic solutions across different scales and timeframes.

To balance the mix of expertise in the project, the design-research team developed an "Ideation Hourglass" framework, shown in Figure 1, to facilitate top-down and bottom-up systems-thinking. Where Moy Park and JF McKenna brought in-depth knowledge of current systems and a focus on the incremental changes towards the project's aims, the academic team brought fresh perspectives contextualised by wider societal shifts towards radical change. The project team met regularly to discuss ideas spanning different scales and timeframes. Discussions were playful and informal, aimed at instilling cross-disciplinary ideation between the industry and academic partners to support new perspectives and mindsets about the current and future state of the poultry sector.

Within this framework, several established design methods were tested, such as the REAP method, which supports bottom-up solutions to reduce, reuse, and produce resources across different scales, and the STEEP method, which aids top-down ideation through social, technological ecological/environmental, economic, and political lens-based analysis [32–34]. During the design phase, the COCD-box method was also used to categorise ideas into how, wow, and now, aiding the team to focus on the development of just a few ideas across the spectrum of feasible, not yet feasible, common, and original [35]. Different types of visualisations, such as diagrams and montages, were used as tools to communicate design ideas and illustrate design methods.

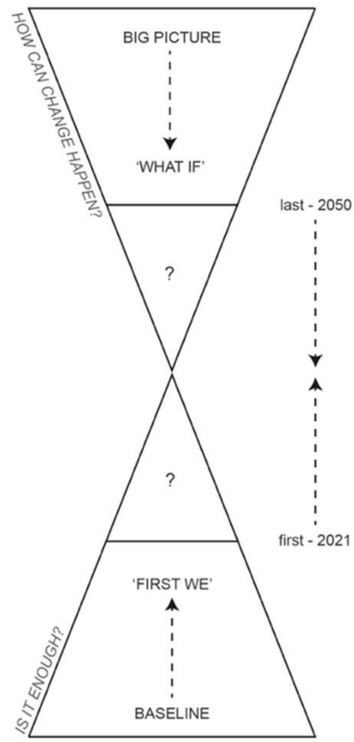


Figure 1. "Ideation Hourglass" framework diagram, balancing bottom-up and top-down thinking to design across timescales.

Here, the challenge of reimagining the poultry house of the future was also used to test research-by-design methods to address complex systems of production by designing spaces based on what flows through them, challenging priorities for building users by shaking up actor hierarchies and redesigning spaces based on new stakeholder dynamics and networks.

Each step in this section informs the development of design propositions, presented in the results, which also function as vehicles to reflect on the research-by-design approaches employed. Here the three design outputs are described through the design approaches used to create them.

3.1. Baseline of Typical Farm Inputs, Outputs, Actors and Networks

The design-research team started the project by carrying out baseline analysis of typical farm spaces and operations, including resource consumption and production. The team also analysed the actors and networks of current operational infrastructures in Moy Park.

3.1.1. Assessing Embodied and Operational Carbon

Assessments of embodied and operation carbon were carried out to understand the environmental impact of poultry housing in the context of the net-zero challenge, a stipulation of the grant funding. First, the team analysed the embodied carbon associated with the construction of a typical poultry house. Through analysis of architectural drawings, and conversations with Moy Park and JF McKenna, the design-research team estimated the quantity of each construction material used in a typical house. Using the ICE embodied carbon database [36], the quantity of embodied carbon per kg of each material type in the base (aggregate, concrete), primary structure (steel frame, timber purlins), walls (façade panels, concrete, polystyrene insulation, double-glazed windows), and roof (tin sheeting, insulation, PVC membrane) was estimated. The exercise revealed that a typical house embodies around 57.3 tonnes of CO_2-eq (tCO_2) and found that the steel structure of a typical house was particularly carbon-intensive material, using just under half of this carbon, at 25 tCO_2-eq per house.

The team also looked at the operational carbon required to heat and power a typical poultry house each year. Due to time-constraints, the team gathered a breadth of rough data on a typical house. For example, analysis revealed that 90% of all houses across the estate used biomass heating, and 75% of those used wood pellets; therefore, the team carried out carbon assessments based on wood pellet biomass heating. Research revealed that approximately 434,000 kWh is required to heat a house per year. The team found that houses heated by wood pellets produce 15 g CO_2-eq per kWh and around 6.5 tonnes of CO_2-eq per year [37]. Researchers found that all houses are powered by N.I.'s grid electricity, which uses around 339 g CO_2-eq per kWh, and each house uses approximately 34,000 kWh of electricity per year, equivalent to 10.5 homes in N.I., producing 11.5 tonnes of CO_2-eq per year [38,39].

Determining that half of embodied carbon in the house corresponded to its primary structure opened reflections on how changing this material to, for example, a timber structure that has lower embodied carbon, could be an easy way to dramatically reduce the embodied carbon in house construction to address net-zero targets. Since the embodied carbon of the primary structure is integral to the house, Moy Park would have to wait until an existing house reaches its end-of-life or adopt lower carbon materials in new houses first. In contrast, the team agreed that it would be easier and quicker to address operational carbon by, for example, adapting the fabric of existing houses to increase thermal mass, to insulate floors and roofs to use and waste less heat. The team also reflected on precedent typologies, mentioned in Section 2.2, to consider more efficient heating and power infrastructures and whether they could be applied in N.I. Dismantling space to focus on carbon, energy or material flows supported these reflections and unlocked new ways of designing the house to rewire these flows. The authors pick up on this point in Section 4.1 of the Section 4.

3.1.2. Assessing Stakeholder Actor-Networks

The design-research team unpacked and visualised other flows, from infrastructural to social, through actor-network mapping. In addition to the carbon assessment of current operations, explicit and tentative relationships between Moy Park and their stakeholders were analysed. Data were collected though informal interviews with sector specialists inside Moy Park's organisation, such as employees working on the management of litter, plastic packaging, and public relations. This informed further desktop analysis of important suppliers, consumers, influencers, and governors.

Modelled on Thun et. al's interpretation of Latour's theory, the actor-network map in Figure 2 was produced to visualise key actors and relationships between them [40]. These were used to inform conversations with Moy Park about how these networks might be manipulated to address the aims of the research project. This method of drawing helped to codify a complex and dynamic web of connections between internal and external stakeholders, providing a system lens for strategic-level conversations around present and future operations.

While Moy Park's internal business structures were clear to employees, relationships with external stakeholder networks were not. As a poultry integrator, the relationship between business and farmer is complex and intertwined, and as such, essential to understand to reimagine future relationships and spaces. One interesting aspect of the poultry integrator's business infrastructure was that the poultry farmers supplying the integrator operated a bit like franchisees, personally purchasing all the necessary ingredients from the integrator to make fully-grown chickens, such as paying for housing, power, feed, and chicks. To determine the boundaries of environmental responsibility, the team asked the organization questions such as, Who owns the chickens? Who buys the feed? Who is responsible for litter management? Who monitors emissions? Visualisations of the whole network and key relationships in that network helped Moy Park to reflect on previously unseen connections for the first time. This opened conversations on partnerships, sharing, and responsibility on issues of resource consumption, waste, and welfare to consider how the house design might respond to or influence these concerns and highlight opportunities to hack these hierarchies to address the project's aims. This approach was taken in the development of the second design proposition presented in Section 4.2 of the Results.

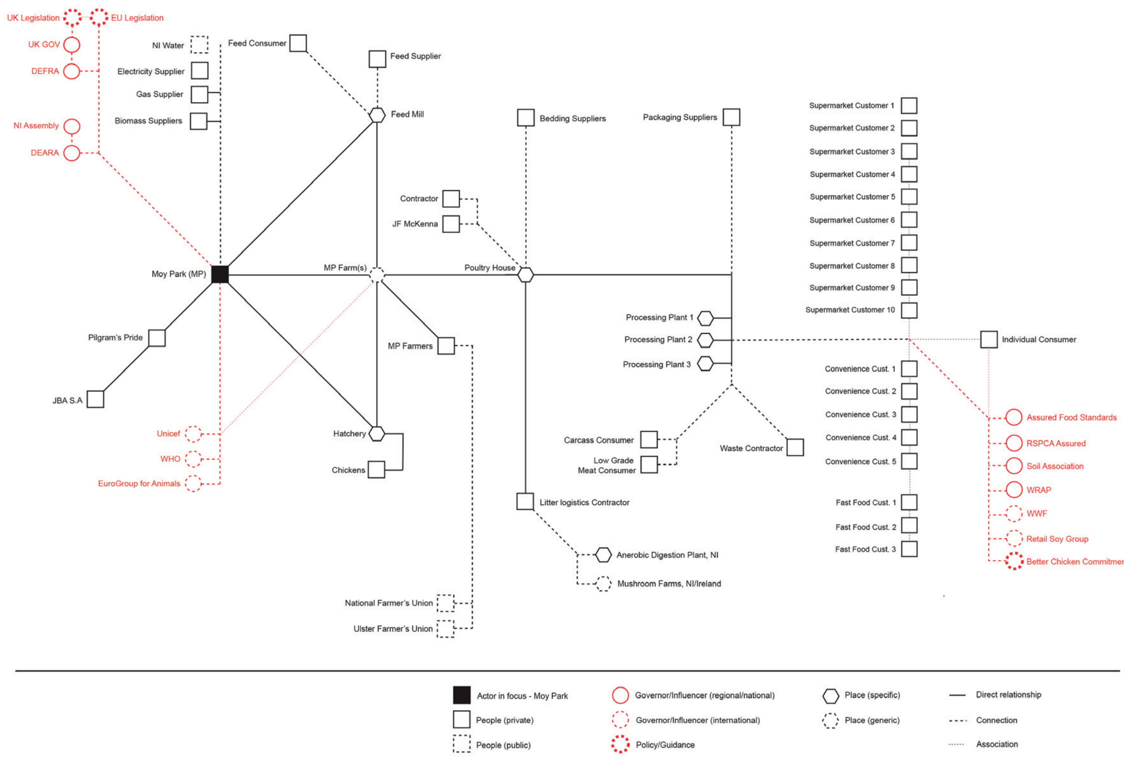


Figure 2. Actor-network map capturing explicit and tentative relationships within Moy Park's business ecosystem.

3.2. Consolidation of Themes and Scenarios

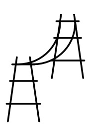
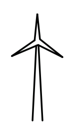
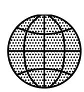
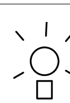
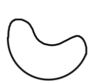
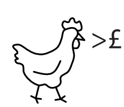
Subthemes in relation to environmental sustainability and bird welfare emerged as a result of the baseline to encourage more holistic inquiry and prompt further research to understand impacts and opportunities for Moy Park. This encouraged the industry partners to see existing conditions through new eyes allowing them to question these in a safe, explorative environment.

The design-research team developed long-term risk and opportunity scenarios using the STEEP scenario-building approach to explore what is happening in societies, including businesses, at local and global scale [32,33]. This informed the development of five themes of interest to the poultry sector. These themes, described briefly below, formed the basis of informal discussions and desktop research across the project:

1. Biosecurity: a review of the seasonal recurrence of Avian Influenza (AI) in Europe and how it might continue to influence the scale and shape of future poultry production as well as perceptions of large-scale livestock production.
2. Emerging technology: research on how technological advances in data management, breeding, and alternative proteins might manipulate future diets and wider consumer culture, redress stockmanship, and alter the scale of production.
3. Animal welfare and changing tastes: assessment of recent developments and projected trends around consumer and retailer awareness and animal welfare expectations and how this might impact future operations, including house design, breeding, and economic models of production.
4. Climate resilience: analysis of projected U.K. climate shifts and how this could impact animal welfare and supply chains, as well as the design of future houses, farms, and estates.
5. Resource use and waste: a review of the resources consumed and produced in current poultry production operations and changing legislation affecting local and global contexts.

Theme-based analysis through scenario-building enabled the design-research team to develop a deeper understanding of core risks in achieving the aims of the project. These were communicated to Moy Park through short descriptions and icon-style diagrams to relay how production operations might be affected in the long-term. These diagrams informed a mnemonic approach, consolidating a collection of complex concerns and ideas into easily understood chunks of information. Compiling key challenges in one, easy-to-read format gave the poultry producer a discussion tool for strategic level decision-making beyond the project period. A selection of potential scenarios and mitigations is outlined in Table 1.

Table 1. Exploring thematic scenarios and mitigations, supported by icon diagrams.

		Scenario		**Mitigation**
Biosecurity		- Major Avian Influenza outbreak		- Lower house densities - Less birds per farm - Minimum distance between farms
Carbon tax		- Poultry farming must become low carbon to be economically viable		- Internalise carbon offsetting - Source materials locally - Reduce waste
Supply chains		- Resource scarcity causes raw material price increases and volatile markets		- Close waste streams - Source raw materials locally - Use resources efficiently
Deregulation		- Cheaper, lower welfare chicken enters market		- Revisit sustainability and welfare branding
Alternative Protein		- Non-animal protein become standard in fast food and ready meals		- Increase consumer transparency - Supply higher welfare chicken

Parallels between themes revealed the complex nature of transitioning the sector to address environmental sustainability and welfare issues, as well as the impact of prioritising some themes over others, and how this might result in radically different future conditions. The research team compared complementary and conflicting themes to combine problems and solutions. These problem-solution framings are described next, ordered in relation to each of the three design propositions presented in the Results section:

- Restricting bird production to indoor conditions could ensure biosecurity by controlling conditions to reduce outbreaks. This approach also controls the flow of waste streams from the house and enables waste to be collected and repurposed to produce, for example, energy or other food products, such as mushrooms. However, an indoor-rearing approach may reduce capacity to improve animal welfare by limiting outdoor access. Conversely, reducing operational energy use and associated costs through natural ventilation opens opportunities to foster indoor–outdoor housing, which could also improve welfare but would mean ammonia emissions are less well controlled.
- Some research suggests poultry producers could rear slower-growing birds to improve welfare [41]. However, these slower-growing breeds would cost farms more because they use more heat and power and consume more feed, which has environmental and economic implications. Farmers could manage this drop in income by, for example, producing complimentary crops, while supermarkets might increase the cost of chicken to reflect increased welfare credentials.
- Emerging surveillance technologies could be employed to reduce workload and potentially address the issue of ageing farmers in the U.K. and N.I. context. Live streams of farm conditions could also be coopted by supermarket retailers to address growing welfare concerns. The poultry house might then be redesigned to become much smaller, if it is no longer entered by people, reducing construction and operational costs. However, this could have negative implications for farmers who might have to pay for the cost of technology. Welfare may also be at risk through loss of stockmanshi skills.

Compromises of one theme over another under the broader context of addressing environmental sustainability and welfare revealed different challenges for different actors within the STEEP nexus. For example, new housing infrastructures require economic investment from individual farmers, which influences the speed of change, while social and political influences could also play a role in catalysing or stalling these changes from the outside. While the STEEP analysis highlighted conflicting challenges, bearing in mind the project's aims, the research team prioritised the ecological/environmental aspect of the STEEP tool as they developed design propositions. In this way, they could employ design approaches to explore alternative systems, spaces, and networks of production unbound from the priorities of current operations. This approach of hacking stakeholder networks is explored further in Section 4.3 of the Results.

3.3. Imagining a Compendium of Multi-Scalar Ideas for the Poultry Farm of the Future

The design-research team used the themes, scenarios, and baseline findings to build a compendium of propositional ideas and solutions to imagine environmentally sustainable, higher welfare poultry farms and housing. The compendium of future scenarios, spaces, and ideas developed organically, often evolving from unstructured conversations. In these instances, problem-framing through "what-if" questions led to thought-experiments: *"If this happened, then what might be the result? How might this impact society, the environment, or economics? If we removed economic considerations, what decisions might be made, and could the environment or society benefit more?"*. From here, the team applied Cross' concept of a creative leap, finding "sub-solutions" to bridge against the framed problem through conceptual thinking [42]. Significant ideas stemming from conversations were recorded and then were informally framed as a research question. This question was then explored by one team member through more rigorous design-based investigations and presented to the design team on a weekly basis for feedback to inform new iterations. This approach worked well, giving time to collaboratively bounce ideas through conversation as well as ensuring progress by formalising one or two of these ideas alone. Working in this way, each individual design-researcher brought different value systems, interests, knowledge profiles, and experiences to their propositional outputs. Presenting these formalised ideas in a group setting challenged these value systems, providing positive criticism through different lenses. This meant that one idea, explored by several individuals, would result in different outputs, and therefore more holistic solutions.

Through the "Ideation Hourglass" framework, the project team balanced top-down and bottom-up actions. Where the top-down approach focused on risks and opportunities as well as external pressures, the bottom-up approach focused on immediate action to identify "low-hanging fruit", or operations that could be easily transitioned to environmentally sustainable or higher welfare alternatives. Aided by the baseline analysis findings, the design-research team used the REAP design method to categorise potential "easy wins" at the house, farm, and estate scale in Figure 3 [34]. Taking a mindset that it is better to fix a little bit of the whole system than perfect just one aspect of it, one change applied at each scale could have a multiplier effect to quickly reduce carbon emissions, waste, or reliance on external supply chains.

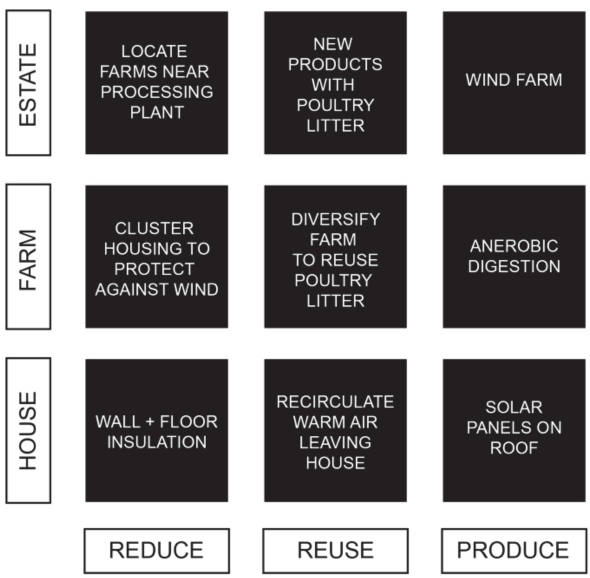


Figure 3. REAP method matrix for categorising bottom-up design ideation.

As research-by-design is iterative, some propositional ideas emerged earlier in the project than others, for example, reviewing typical annual energy use to power a poultry house prompted testing of the potential energy production if solar panels were to be installed onto its roof. Equally, some ideas were developed further than others, while others remained abstract or focused on a certain aspect of the project's aims. In addition, as is typical in design-research, evaluative thinking ensured that problems and solutions co-evolved across the project. For example, development of the propositional ideas incited further baseline analysis as well as further theme definition and scenario-building [26]. Themes placed at the centre of the divergent–convergent thinking process funneled the development of further ideas, while also helping the design-research team to focus on developing just a few ideas more comprehensively. The COCD box method was also used to facilitate critique and design decisions to develop the three propositions [35].

In all instances, each relevant idea was recorded and communicated through a range of drawing formats including diagrams, maps, timelines, collages, orthographic drawings, and sketches with one example provided in Figure 4. The design-research team applied a familiar visualisation approach that combines the production of diagrams and photomontage-style collages to communicate core design ideas and give a sense of how these ideas play out spatially [43]. Read together, both drawing types communicate complex ideas holistically. Read in context, they capture views of an imagined scenario combining existing and future worlds. Drawing across the formats described prompted on-demand decision making: "*How big is the future house in its landscape? How does light enter the space? What type of food is the chicken consuming?*". Once complete, the image supports further reflection on the type of space imagined and whether it effectively addresses the challenges. Like the scenarios described in the previous section, this approach worked as another visual mnemonic to explore many solutions to various parts of a complex design problem. Further examples of the different drawings produced are shown in the Results section of this paper.

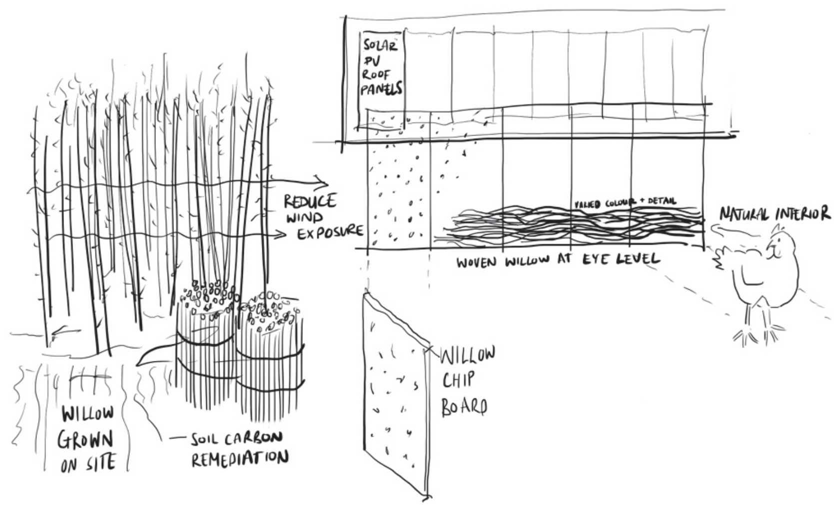


Figure 4. Sketches depicting early ideas on embedding circularity within the poultry house design and wider farm operations.

4. Results

The research-by-design methods applied across this project aimed to generate a way of looking at current and reimagining future poultry house architectures to address environmental sustainability and bird welfare in poultry production. Here, the challenges faced by the poultry sector are tested, with the overarching aim of finding design approaches to examine and unlock pathways to reimagine complex locked-in systems of production.

As indicated in the previous section of this paper, the last step in the approach informed the development of a compendium of design propositions to address these aims. Following the generation of five key themes in Section 3.2, a compendium of disparate thematic design ideas was synthesised to the design and visualisation of just three propositional futures for poultry production, explored in this section. Each proposition emerged from lens-based investigation of two of the five themes identified in Section 3.2, as indicated in Figure 5, to inform house designs with different priorities relating to the overarching challenges.

The propositions, named *Circular Chicken, Happy Chicken,* and *Network Chicken*, are described below—less as finished projects or optimum visions for the future of poultry housing, and more as vehicles to describe the different research-by-design methods employed in the project to address its overall aims. These propositions are described under the umbrella of the design approaches employed in the project, for example, the *Circu-*

lar Chicken proposition highlights how the designers shifted their focus from space to flow design.

Figure 5. Icon images indicating how different themes, described in Section 3.2, were combined to generate different scenarios for the future of poultry farming and housing.

4.1. Dismantling Space to Flows

Baseline analysis of the typical poultry house, highlighted in Section 3.1.1, revealed the carbon emissions associated with construction materials, heating, and power supply. This revealed that the constant stream of resources used to operate the house outweighed the one-time impact of constructing the architectural artefact, and as a result, dismantled the initial view that, to achieve net-zero, the house must first be redesigned. This highlighted the need to redesign the house's flows rather than its spaces.

The difficultly of reducing emissions associated with operating the house since, for example, Moy Park is unable to decarbonise external heat and power supply, was also highlighted. This opened conversations around how they might use existing waste streams within their estate to localise heat and power supply, for example, through anerobic digestion of poultry litter. The team also discussed how Moy Park might take advantage of the large roofscape on existing poultry houses to install solar PV panels to build some resilience against the rising price of heat and power supply. The team reviewed the types of technologies required to support this shift, such as battery storage, and how Moy Park might share excess energy production through cooperatives with residents in rural N.I. Further baseline research on the impact of waste outputs, such as poultry litter, revealed unseen environmental damage, which informed conversations around how to promote more sustainable resource supply, use, and management in line with UN (United Nations) Sustainability Goal 12, Responsible Consumption and Production [44]. This shifted priorities away from the initial focus on net-zero, laid out by the funding body, to address environmental sustainability in a more holistic way. All of the above were ingredients in the development of *Circular Chicken* proposition.

Abstracting typical poultry farm operations into a system of resource flows, shown in Figure 6, the *Circular Chicken* poultry house was reframed as a container for inputs and outputs from the perspective of material flows, such as water, to nutrient and chemical flows, such as ammonia. The proposition explored ways to valorise poultry litter, taking ammonia and waste heat from poultry litter for aquaponic production of high value crops. It looked at an existing waste stream from anerobic digestion, a liquid called digestate, and how this might be used to produce micro-algae to feed insects and localise poultry feed or make biomethane for the poultry integrators fleet. It also looked at ways to make mycelium packaging from mushrooms grown in poultry litter and how urban forestry might be used to localise bedding supply. This proposition not only revealed the economic value of existing waste streams but also expanded the houses' boundaries, reconnecting the scale and impact of resource use and waste with global ecologies.

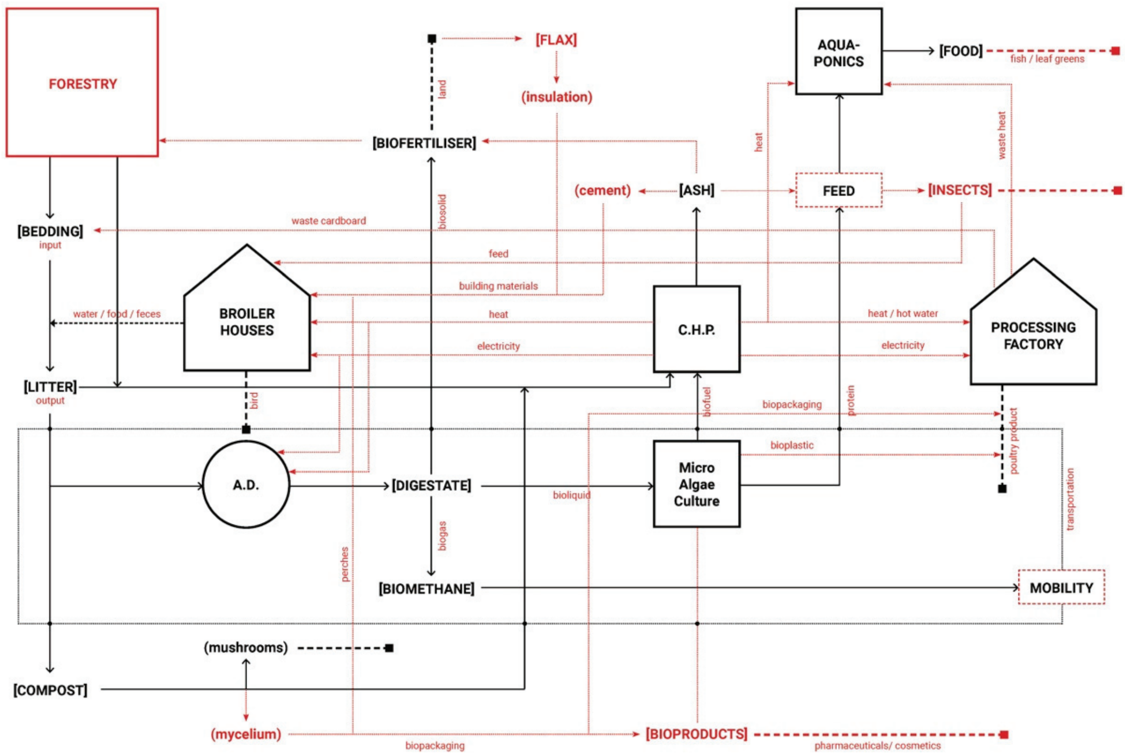


Figure 6. Diagram exploring potential material flows to reduce waste and create new economic opportunities. Research for this diagram was funded separately by CIEL to Moy Park.

Reflecting on the existing linear model of poultry production, the design-research team applied circular economy principles to reimagine the future poultry farm as a system of closed loops. The proposal was first described through abstract flow diagrams and sketches. Then through collage images, shown in Figures 7 and 8, visualising the interventions required to facilitate waste-free on-farm production, such as an offset forest and micro combined heat and power plant (CHP). Discussed together, they highlighted the value of designing whole-system interventions that go beyond the redesign of spaces or the installation of technologies. The visualisations opened conversations around the scale of these interventions, whether it is possible to, for example, have an anerobic digestor on each farm or whether one needs to be available to multiple farms in an area to make this option more economically viable.

Viewing productive businesses such as this one as a global resource manipulator, the proposition also opened questions about how Moy Park should respond to current and future climate legislation around carbon accounting, and how the design of poultry housing might help the farm, rather than the business estate, to become an accounting boundary, halting the flow of waste streams beyond this boundary and optimising flows to create new spin-off income streams, such as through the production of mushrooms or algae while targeting existing issues of environmental pollution, such as eutrophication.

Figure 7. Sketch section exploring relationships between potential architectural, infrastructural, operational, and technical components on a future "circular" poultry farm.

Figure 8. Elevational collage depicting what a "circular" farm might look like and contain.

4.2. Restructuring Actor Hierarchy

Spatial analysis of the evolution of Moy Park's housing revealed that bird welfare is addressed incrementally within the existing large-scale, tech-centric housing model to ensure high levels of biosecurity. Working closely with poultry behaviour experts, the design-research team developed the *Happy Chicken* proposition, shifting priorities towards welfare and climate resilience, two of the five themes in Section 3.2.

The team played on common architectural practice approaches by developing a client brief for a chicken, which functioned as a tool to give a voice to a silent, non-human actor in the productive system. This playful approach to engagement and brief-making temporarily re-orbited dynamics away from business priorities, providing a flattened hierarchy to expand conversations beyond the current state-of-play. This approach set a mission for the design-research team, animal behaviour, and welfare experts as well as Moy Park and JF McKenna to come together to understand and design for a chicken's dietary, lifestyle, and environmental preferences. Numerous discussions with experts and farmers revealed that, like humans, chickens have different personalities, for example, some are more active and playful than others. Spatial analysis of several types of internal, external, and hybrid housing systems enabled further conversation around designing for chicken happiness. This research was visualised through a series of chicken profiles detailing, for example, how chickens play, what they eat, and daily routines, shown in Figures 9 and 10.

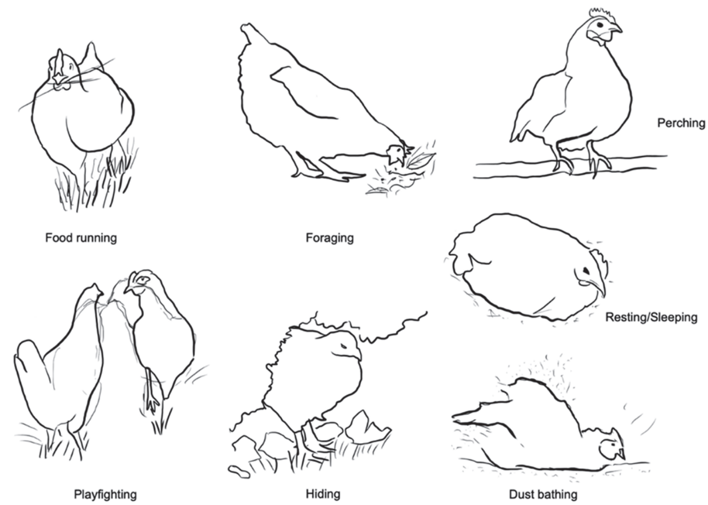


Figure 9. Sketches developed with poultry welfare experts to facilitate conversations around internal poultry house design ideas.

Name	Age	About me	Hobbies	Favourite memory	Favourite time of day	When I'm most scared
 Jo	37 days	Broiler chicken	Food running Dust bathing	When I jumped on top of straw bales	When I take a stroll in the morning	When the humans caught my friend

Figure 10. Sample bird persona developed with poultry welfare experts to facilitate conversations around bird behaviours and preferences across age and breed.

Illustrated in Figure 11, initial ideas focused on creating an integrated forest housing system to resituate more resilient, slower-growing chicken breeds in their indigenous environment, support the immediate offsetting of carbon emissions, and diversify farm income through short coppice crop production. Inspired by organic practices, a time-based design strategy imagined that the future poultry house could be situated within a new forest of oak standards, infilled with hazel coppice. These houses would be constructed from local timber and designed to move through the forest at the end of each production cycle. Flexible netting pulled between trees would allow the chickens to be in a protected outside space within nature. The movement of houses across the forest would be timed to coincide with coppicing and sequenced to fertilise the ground appropriately, while at the same time managing the risk of contamination between flocks.

Retaining the chicken as a key actor allowed the design-research team to question existing processes and scales of production. The proposal opened debate about how designing for bird happiness, through nature-based solutions, may incur higher economic costs. The proposition highlights the biosecurity risk of allowing chickens to live outdoors and seeks to offset this with smaller flocks of more resilient breeds. At the same time, the proposition presented opportunities to diversify income, improve supply security, and support recognisable consumer branding as well as rapid carbon descent through reforestation. Attaching a mission to the design strategy through discussion-based fact-finding and profile-building proved effective in helping the poultry integrator to remain open to seeing the value of solutions that were different from current modes of production. Shaking up actor hierarchies opened opportunities to see Moy Park's operations from a previously unconsidered perspective, even if this approach was deemed economically unviable for current scales of production.

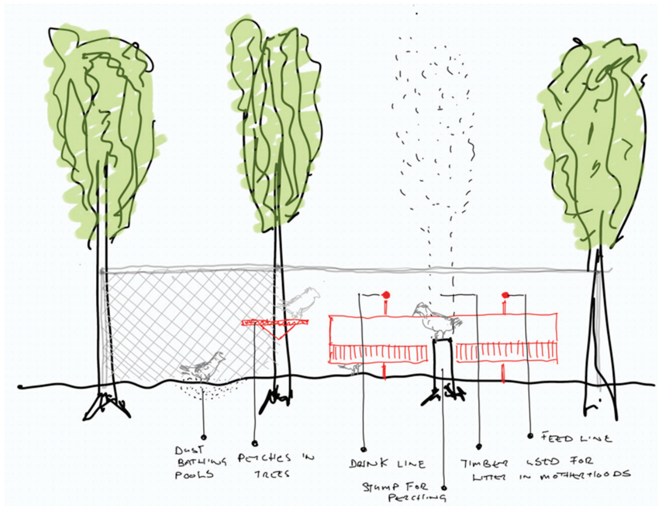


Figure 11. Early sketch proposal for a moveable house in a forested environment that repositions the chicken as the primary client.

4.3. Hacking Stakeholder Networks

Researching U.K. supermarket targets, Moy Park's key customer, revealed plans to increase the number of sustainable, higher welfare meat products as well as plant-based products in stores. For example, Tesco aims to source all soy from deforestation-free regions by 2025, and in the same period, plans to increase sales of plant-based alternatives by 300% [45]. Similarly, research by LIDL suggests that 71% of their shoppers want retailers to be clearer about how the chicken they purchase was raised and 68% of 16–24-year-olds are drawn to plant-based diets [46]. Unpacking these targets created a framework to understand emerging and future expectations around poultry production. Stakeholder mapping, described in Section 3.1.2, supported this notion of the supermarket as the frontier for market access. It also highlighted the complex economic relationship between the integrator and individual farmer, and how this could support or hinder rapid business transformation.

Parallel conversations across the study focused on the importance of maintaining biosecurity and the integrator expressed interest in maintaining a centralised, indoor housing environment to address this concern. Reflecting on the changing consumer-food dynamic, the design-research team sought to reframe this "red line" to imagine a smaller, distributed model for poultry farming, based on creating outbreak exclusion zones to reduce contamination risks and smaller flocks to reduce economic risks if disease outbreaks occur. The *Network Chicken* proposition, visualised in Figure 12 emerged from this concept of designing small, seen, and secure housing. Challenging current centralised models, the concept supports better connections between consumers and their food's provenance. Suitable for urban, domestic sites, the consumer becomes the farmer and custodian of the flock. Managed through artificial intelligence (AI), fed with domestic food waste, monitored by roaming "expert" farmers and visited by a mobile abattoir; the house, or coop, shrinks the gap between consumers and food to enable transparency and visibility in the food-chain. This proposition addresses environmental sustainability through the use of food waste, reducing the need to source feed globally. The proposition raises questions around how this model could be managed, who would own the chickens, and how much would they cost.

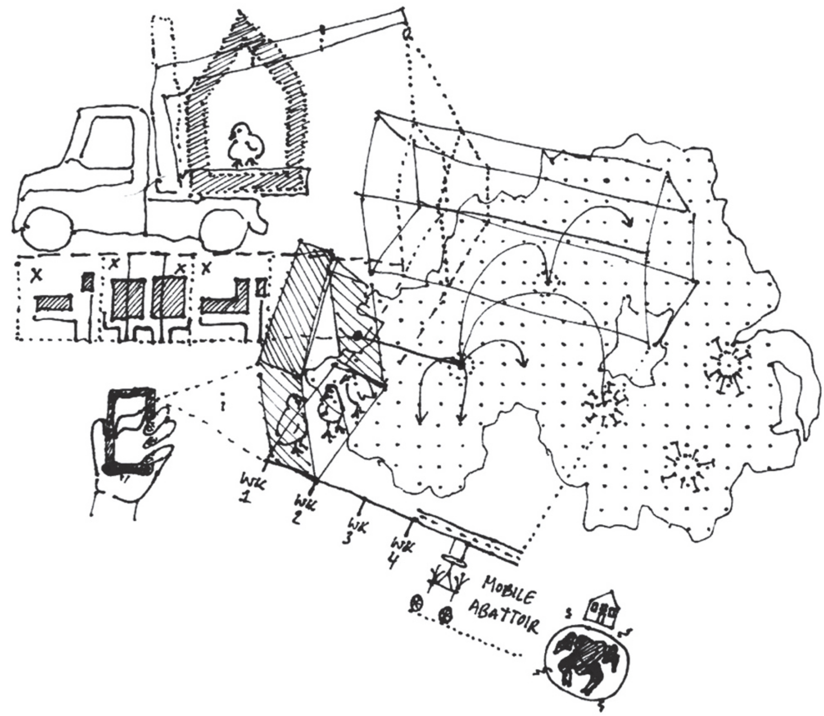


Figure 12. Early concept sketch proposal for a distributed network of small houses across N.I, monitored and managed by consumers using app technology.

Rather than think of this proposal as an artefact, the design-research team combined current and future priorities of several stakeholders, such as Moy Park's desire for biosecurity and the consumer's desire for transparency. Using icon-style diagrams such as those shown in Figure 13, the team communicated a mix of external influences potentially impacting poultry production. Amplifying these priorities, the *Network Chicken* proposition is extreme and tied to significant cultural and technological leaps. Despite this, it served well to help the wider research team to reflect on how internal and external stakeholders might shape the future of food production and consumption, develop an awareness of the type of emerging technologies likely to catalyse shifts, and explore how current business operations help or hinder rapid changes.

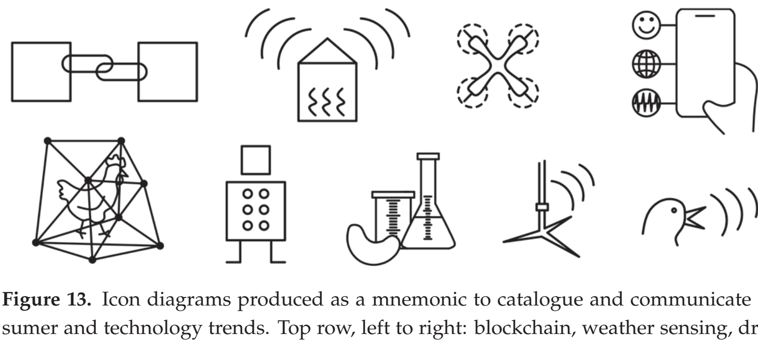


Figure 13. Icon diagrams produced as a mnemonic to catalogue and communicate shifts in consumer and technology trends. Top row, left to right: blockchain, weather sensing, drones, off-site management, Internet of things, robotics, alternative protein, RFID-tagging, welfare sound sensing.

5. Discussion and Conclusions

5.1. Reflections on the Design Methods Used

Across the project, the design-research team used systems thinking to find pathways from problems to solutions to address the challenge of designing a more environmentally sustainable, higher welfare future poultry house, recognising the "wicked" and complex nature of the challenge. Reflecting on established design methods, the team structured the design process into three iterative, interlinked steps which, starting with baseline analysis of farm inputs, outputs, actors, and networks, then developed themes and scenarios and finally a compendium of solutions. Within each step, a range of design methods, including STEEP, REAP, and the COCD box, were deployed to develop and test ideas. An "Ideation Hourglass" framework supported the development of top-down and bottom-up solutions. Spanning the long and short-term, this framework bridged complementary and conflicting concerns to gather a range of ideas from across the interdisciplinary design team. Different types of visualisations were used as devices to communicate and critique ideas in project team meetings. Diagrams were particularly useful in communicating complex challenges and ideas in an accessible format. Visualisations also flexibly communicated solutions for both near and far-future queries.

Applying different lenses of investigation to the house led to a variety of scenarios and three design propositions exploring the future of poultry housing. Named *Circular Chicken*, *Happy Chicken*, and *Network Chicken*, each proposed radically different futures arriving from an exploration of different themes and scenarios and reflections on the baseline findings. Each proposition also tested different design methods. The *Circular Chicken* proposition emerged by shifting the focus away from the design of space to the design of flows. Reflecting on the baseline carbon assessment of housing, which found that the carbon embodied in a house with a 30-year lifespan is much less than the carbon to heat and power housing annually, this design proposed integration between house, farm, and estate to enable resource efficiencies through circular economy principles. The *Happy Chicken* proposition restructured actor hierarchies in the poultry production system to design the poultry house for its primary occupants, and then speculated on ways to make this economically and operationally viable. The final proposition, *Network Chicken*, is a reflection of the stakeholder mapping carried out in the baseline analysis. It explores how external actors and technologies might enable decentralised models of production that are bio-secure and better connected to consumers.

Rather than attempt to realistically determine one future poultry house, the propositions tested design methods to explore the future of specific, emerging trends already impacting the poultry production sector. Analysing the poultry house by what flows through it, how it connects to actors-networks and could be impacted by societal shifts revealed that a poultry house is not just a piece of real estate; it is also a home for chickens, a consumer of biomass, a producer of protein, and a node along a supermarket supply chain. By zooming in on the poultry house through different lens, the design approaches taken offered a route to recognise the complexity and interdependency of the challenge yet quickly generate spatial solutions to support changed mindsets that start to break away from locked-in systems. This approach revealed the difficulty of the challenge and that there is no right or clear answer for how the future poultry house should be designed, particularly in the context of climate change and consumer shifts. Though not explored in the scope of this paper, Moy Park carried out sensitivity testing and an internal economic assessment at the end of the project to inform investment strategies. Some of the ideas arising from this project informed contingency planning and strategic visioning while others spurred further in-house research activities on specific environmental sustainability and welfare challenges.

5.2. Designing in a Changing Context

Undertaking this study through the COVID-19 pandemic and during the Brexit transition period highlighted the speculative nature of planning for the future within an uncertain present. Global events such as this revealed how quickly some trends accelerate while others dissipate or change. Throughout the project, the concerns of climate change and the vulnerability of the sector to global supply shocks became immediate and apparent to all partners, particularly the poultry integrator. These events included Northern Ireland recording its hottest day on record during the summer of 2021, a shortage of key workers and drivers, reoccurring AI outbreaks, increasing energy prices and a shortage of CO_2, all critical to the poultry sector. In addition, the UN's 26th Climate Change Conference highlighted rapidly changing global and local legislation shifts towards environmentally sustainable, high-welfare food production [34,35]. These pressures exposed the fragility of current practices and processes, highlighting the reliance on linear supply chains and tangential industries that are politically, economically, and environmentally volatile.

5.3. Fostering Interdisciplinary Collaboration

While the research did reveal some interesting ideas and trajectories for poultry production and consumption, one clear benefit of the design methods used was that it supported industry partners to form new perspectives about their sector's future, though aided somewhat by the timing of external events during the project. The design approaches taken helped Moy Park and JF McKenna crash-test pathways to change, shifting from incremental to rapid, radical shifts and identify ways to make "more good" in how Moy Park's operates, rather than tweaking existing systems to make things "less bad" [33]. In a sector that is continually in production, time and effort tends to be spent dealing with problems in the immediate term. This project provided industry partners with the space to consider the day to day in the context of bigger future challenges.

The design-research team tested ways to foster collaborative ideation with industry partners during team meetings. For example, at the beginning of the project, the team started by explored far-future what-ifs rather than unpacking the existing architecture. This approach dismantled the wider team hierarchy bringing everyone together to see problems associated with current production practices by first thinking of big-picture solutions. Discussions remained intentionally informal and playful, often peppered with silly questions challenging the status quo to invite collaborative reflection and build consensus. Together with the methods, this design environment enabled industry partners to "see the forest for the trees", to play out different scenarios without risk, co-create better models based on different value systems, and to map pathways to implement these in future operations.

5.4. Limitations to the Research-by-Design Methods Used

The spectrum of opportunities that design can unlock—the possible versus the probable—also presents a limitation. The method, shaped by questions of "what" or "who" is placed at the centre of the challenge and is fundamentally determined by the designer's ethical and theoretical position. For example, placing the chicken at the centre of the brief produces a radically different solution to one that places a technology at the centre of the challenge. It is not to say that one approach is better than the other, but that the full spectrum of opportunities can never fully be realised because of the bias that underpins the approach of those involved in the design process. Furthermore, the design methods used throughout this research work require time and space to explore around and beyond the immediate question at hand. In industry, limited time and resources mean that this is not always possible. As such, ensuring mechanisms for exploring the capabilities offered by analysing long-term opportunities is vital in industry and academia. Equally, industry partners must be open and transparent with information and actively engage in the ideation process. Naturally, this openness can lead to tough questions and even tougher solutions.

5.5. Future Work

This paper highlights the value of research-by-design to reframe, reimagine, and visualise solutions addressing interdependent problems within the poultry sector. The design-research team used an explorative approach, testing a mix of design methods and visualisation techniques within a framework that spanned different scales and timeframes. Informal, playful discussions within the project team fostered ideation between academic and industry partners, bridging top-down and bottom-up action. Further work could expand on the baseline analysis findings or explore further propositional ideas about the poultry house, based on new combinations of themes and scenarios. More work is also required to understand how the design approaches explored in the Results, such as dismantling spaces to flows, might be optimised or compared against one another. Finally, this paper also highlights interesting insights into the value of design-led collaboration between academic and industry partners to consider the future of complex systems.

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Conflicts of Interest: The authors declare no conflict of interest.

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Article

Conceptual Design in Informal Metalworking Microenterprises of Tanzania

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Abstract: Product design is a key aspect of human intelligence and creativity, attracting not only experts but also people without any formal design training. Although numerous people in developing countries design and manufacture products in metalworking microenterprises in the informal sector, there is still little knowledge about their design process. This paper aims to fill this gap in design knowledge. We aim to investigate the design processes in metalworking microenterprises in the informal sector of Tanzania. In particular, we aim to explore how these microenterprises identify consumer needs and requirements, how they determine the specifications for the product, how they generate and evaluate alternative product concepts, and how they define product details. To address these aims, semistructured interviews were carried out in metalworking microenterprises operating in the informal sector of Tanzania. The findings reveal many facets of their design processes, providing a sound basis upon which design methods and tools can be developed to support their design activities.

Keywords: conceptual design; design practice; informal sector; microenterprises; sustainable development; developing countries

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1. Introduction

People around the world are increasingly living in artificial designed environments proliferated with a wide range of designed products, such as electronic gadgets and vehicles, as well as relatively simple products such as kitchen utensils, bicycles, furniture, etc. Design activities and their outcomes profoundly affect our lives and well-being, while impacting social and environmental sustainability, plus the economic growth of organisations involved in design, manufacturing, and other life cycle phases of products [1]. Humans have designed many kinds of products in the past; they are doing this presently and will engage in design activities in foreseeable future as well. Whilst people with formal design education might have more abilities to design products, those lacking formal education also have abilities to design a broad range of products [2–4].

Design processes offer opportunities to design products that satisfy intended requirements while minimising unintended consequences [5]. As such, the scientific field of "design research" not only aims to gain an in-depth understanding of design processes, but also aims at their improvement [1]. As design is a context-sensitive activity [2,6], there is a critical need to investigate design processes in a broad range of contexts representing various social, economic, and cultural characteristics.

However, extant design research has predominantly been undertaken in some specific contexts, typically those found in developed countries and relatively wealthy regions of the world. This has generated limited design knowledge in a narrow range of contexts, while restricting our understanding of design phenomena in the resource-constrained settings observed in developing countries [2]. This biased contextual focus of extant design research is not just unhealthy for the growth of design research, but also hinders practitioner ability to learn from design phenomena in various contexts and to design products and services for addressing various global challenges. It is therefore crucial to investigate design activities in developing countries, including design activities in informal metalworking microenterprises [2].

Because there are many socioeconomic and cultural differences between organisations in Western countries and those of the developing world, there are large disparities in their approaches to design and how they design products [2]. Knowledge about design activities in informal metalworking firms in the developing world is needed for developing tailored training programmes and methods to support them in designing more successful and sustainable products.

Enterprises in the informal sector provide income-generation opportunities to nearly one-third of the nonagricultural global workforce [7]. Previous research in this field suggests that microenterprises make up a major part of the informal sector. In general, an organization is considered to be a microenterprise if it has no more than 10 employees, and if the majority of its employee are engaged in the manufacturing of products [8,9].

Design research, presently, is conducted largely in developed countries [10], in organizations that are highly dissimilar to informal metalworking firms in the developing world [8,11]. Thus, there is lack of systematic knowledge about design activities in such metalworking microenterprises. This research aims to address this gap in design knowledge. We address this overall aim by attempting to answer the following two broad research questions, namely (a) how do informal metalworking firms in developing countries elicit client needs and identify requirements for products? (b) How do these microenterprises develop design concepts and define detail designs, including materials, dimensions, etc.? To answer these two research questions, we conducted interviews in 24 microenterprises in the informal sector in some selected regions of Tanzania.

Following the above introduction, the remaining paper is organised as follows. Section 2 reviews the related literature, highlights the need to investigate design activities in a broad range of socioeconomic contexts, discusses the role of the informal sector in developing countries, and identifies the crucial need to explore design activities in informal metalworking microenterprises in developing counties. Section 3 provides the details of the research method, presenting information on sampling, data collection, and data analysis. Sections 4 and 5 present the findings of a qualitative analysis of interview data collected from 24 informal microenterprises. Finally, Section 6 discusses the findings, along with concluding remarks and limitations of this study.

2. Background Literature

This section presents the literature review on the design process and design research, specifically in the context of product design in informal sectors. This review was conducted using a semisystematic approach [12]. An author of this work has previously published an integrative literature review in the domain of design and poverty, specifically on role of poor people in formal and informal design sectors [2]. This integrative literature review guided the semisystematic literature review in this work. This ensured that appropriate literature is accurately covered to be able to answer the research questions.

2.1. Design Process and Design Research

Designed products are recognized as one of many important means for a society to advance its economic and social well-being [1,5]. As individuals, we appreciate a well-designed product, and respond to it by selecting it from available products [1]. The ability of individual entrepreneurs and the industry at large to design efficient, inspirational, and aesthetic products is therefore crucial. The ability to design products is recognised as one of several forms of creativity and a fundamental aspect of human intelligence [3,4]. Consequently, it is important to understand what people do when they exercise design ability [13].

In design research, in order to fully understand how people actually design products, empirical data on the design process are collected by using a variety of methods, including interviews [3,10]. Some characteristics of design processes have been widely observed. It is commonly accepted that the design process is iterative [14,15] and that identification of consumer needs, the generation and evaluation of concepts, and defining of product details are important activities in a design process [2,14,16].

A large body of research has demonstrated that the design process provides a maximum scope to improve, modify, and create new products because many crucial decisions are made in this very process [3,5,13]. Deeper scientific knowledge on the design processes is needed to develop design knowledge [1,13]. Several authors argue that generating design knowledge requires investigating design processes in a variety of settings, covering a broad range of sociocultural and economic environments in which the products are designed [17,18]. However, despite the prevalence of design activity, extant design research is predominantly focused on individuals and enterprises in developed countries, thus investigating design processes in some specific socioeconomic and cultural settings [8,10]. This narrow focus of design research has constrained the generation of design knowledge by limiting its focus [8,10]. Addressing these gaps in the existing design knowledge necessitates that design research be undertaken in a range of fields, including, among others, informal sector microenterprises in developing countries. Such microenterprises are distinctly different on many dimensions from enterprises in developed countries.

2.2. Informal Sector

Low-income people in developing countries may produce a variety of products, such as furniture, utensils, and common domestic goods. These activities of making products create jobs, supporting them to satisfy their unmet or under-served needs [2].

In developing countries, people generally work either in the informal or formal sectors. A person working in the formal sector has a formal contract with the firm owner or employer, typically receives a decent monthly salary, and generally has access to a social security system [2]. In contrast, a person working in the informal sector typically lacks legal contract with the firm owner or employer, lacks a well-ordered work environment, has an irregular work duration, typically receives a low and irregular income, and has no access to social security [2,19].

As mentioned earlier, researchers from sociology, anthropology, and economics, as well as from other disciplines, have extensively studied the informal sector [18,20]. Furthermore, in recent years, studies have been carried out on firms operating in the informal sector [19,21,22]. However, research devoted to this subject is relatively minor as there is widespread commonness of informal firms in developing countries. Recent studies suggest that the contribution of the informal sector to the GDP in developing countries is about 40–60% [23]. The informal sector employs just under one-third (31.5%) of the nonagricultural workforce around the world [2]. As such, the informal sector represents a large segment of the total global economy. For some authors, informality is a "voluntary" choice [24], whereas, for others, informality is an "exclusion" [25].

Some scholars have examined the informal sector as a labour phenomenon [22,26], examining its role in creating jobs for numerous low-income people in developing countries, as well as its failure in providing access to various benefits, including social security. Other scholars have dealt with the challenge of how to describe and define it, its relationship with other parts of the economy, and how it affects growth [7,27]. In addition, some researchers have studied the informal sector as microenterprises, which can benefit from the provision of technology and funding [28]. These studies suggest that microenterprises make up a significant fraction of the informal economy, and most of these firms manufacture products [8,9]. To sum up, the informal sector is a significant part of the total economy in developing countries. However, design researchers have given little or no attention to this sector, despite the presence of product design activities in this sector [2].

2.3. Product Design in Informal Microenterprises

Researchers generally agree on the main traits of manufacturing microenterprises operating in the informal sector. They typically use readily available tools and equipment, are labour-intensive, depend on family ownership, rely on competitive and unregulated markets, and are small-scale [2,29]. They face many constraints, such as lack of access to financial and material resources, weak infrastructure, weak marketing and organisational resources, and absence of specialised knowledge and skills [8,29]. Despite these constraints, studies have suggested that informal microenterprises have the ability to design products [8,9,30–34].

Despite the acceptance of design ability in microenterprises in the informal sector, there is little or no research on their design activities. This can partly be clarified by the perspectives of the studies undertaken in the informal sector. These studies are generally undertaken from an economic perspective and consider design activities of the microenterprises as a "black box" [2,8,9,34]. A recent study has identified the need to investigate design activities in informal microenterprises, including metalworking informal microenterprises [2].

3. Method

In general, design research studies use the following research methods: (a) design experiments; (b) questionnaire analyses (online and offline); (c) interviews (online, physical, or telephone); (d) diary studies; and (e) observational studies in real settings.

In this work, we have used interviews as a research method to collect data. These interviews were conducted in a real setting. This allowed us to obtain the first-hand experience of the facilities available with these firms. Additionally, we saw the products designed by them and had access to their documents, such as sketches, photos, and design drawings. This also allowed us to dynamically react to the responses and further probe, if required, through open-ended questions—something not possible in the design experiments and questionnaire analyses that are usually conducted in lab settings. Similarly, conducting diary studies or 43 observational studies in real settings for 24 firms would have been time intensive.

The interview method—which is widely used in design studies [35]—was used in this work to explore how designers elicit customer needs; how they formulate requirements for products; how they generate, evaluate, and select design concepts; and how they specify product details. Interviews took place between March 2021 and January 2022.

Random-sampling technique was adopted and used to select 24 informal metalworking microenterprises in the Coast and Dar es Salaam regions of the United Republic of Tanzania. The microenterprises in which interviews were conducted were randomly selected to avoid biases and to ensure that the eventual findings approximated those of the actual population. All the interviewed microenterprises were informal metalworking microenterprises, with no more than ten permanent employees. Direct communication and chain-referral sampling approaches [35] were used to recruit interview subjects. Table 1 presents the information on the selected microenterprises and the subjects who participated in the interviews. The major job orders that informal metalworking microenterprises receive include supplying building construction resources (e.g., aluminium windows, door frame grills, aluminium door frames, steel gates, doors, movable kiosks, office space partitioning, and window grills), metal furniture (e.g., bed frames, reading table frames, dressing tables, chair/couch frames, and TV stands.), household utilities (e.g., cooking utensils, charcoal cooking stoves, and charcoal grill stove), agricultural equipment (e.g., chicken feeding utensils), and light machinery (e.g., grain shelling machines, flour milling machines, and brick-making machines)—see Table 1. Figure 1 shows examples of products produced in studied microenterprises.

Table 1. Information on informal metalworking microenterprises and on interviewed participants.

	Firm Attributes				Information on Participants (Two from Each Firm)		
Firm		Firm Age (Years)	Products Manufactured	Number of Staff	Education	Age (Years)	Total Experience (Years)
A	1	2	Agricultural machines, metal windows, door frames, etc.	4	Bachelor's degree (engineering) and O level	27, 35	4, 1
B	2	3	Agricultural machines, door frames, etc.	3	Bachelor's degree (engineering) and vocational training	25, 20	3, 2
C	3	20	Furniture, tables, chairs, beds, and couches	4	Vocational training and STD II	30, 24	8, 3
D	4	9	Furniture (chairs and bed frames), doors, shoe stands, and window grills	5	Both subjects—STD VII	26, 24	8, 2
E	5	15	Door and window grills and furniture	3	Both subjects—STD VII	32, 22	15, 3
F	6	5	Aluminium windows, doors, and aluminium-frame furniture	6	Both subjects—STD VII	25, 28	8, 2
G	7	6	Charcoal stoves, barbeque ovens, water gutters, and metal suitcases	2	Both subjects—STD VII	30, 22	9, 4
H	8	6	Bed frames, door grills, and steel gates	2	Bachelor's degree (business administration) and STD VII	32, 20	9, 1
I	9	2	Door and window grills, bed frames, chair/couch frames, and movable kiosks	4	Both subjects—STD VII	22, 21	3, 2
J	10	2	Chicken feeding utensils, charcoal stoves, and metal suitcases	2	Both subjects—STD VII	30, 15	7, 1
K	11	3	Bed Frames, window grills, door grills, dressing table, gates, decoration stands, and dressing tables	7	STD VI and STD VII	28, 23	6, 2
L	12	11	Window grills, door grills, and fence gates	3	STD VI and STD VII	22, 28	3, 10
M	13	8	Gates, window grills, furniture—bed frames, table frames, chairs	4	STD VI and STD VII	23, 32	3, 8
N	14	8	Window grills and furniture—bed frames, table frames, chairs, etc.	4	VETA and STD VII	35, 30	10, 9
O	15	6	Aluminium windows and doors	8	BA degree—public relations and form IV	32, 27	5, 3
P	16	1	Widow and door grills, fence gates, and bed frames	4	Artisan (vocational training) and form IV	29, 23	15, 6
Q	17	7	Aluminium widows and door grills and partitioning of rooms	20	Form IV, diploma in public administration	20, 24	2, 5
R	18	6	Aluminium widows and door grills and aluminium wardrobes	4	Form IV and form IV	24, 27	5, 2
S	19	7	Flour milling machines, grain shelling machine, and grain processing machines	4	Bachelor degree in education and diploma in mechanical engineering	26, 51	5, 2
T	20	3	Door and window grills, bed frames, and fence gates	5	STD VII and STD VII	23, 22	7, 1
U	21	2	Aluminium profiled doors and windows, aluminium furniture, and deck rails	7	Form IV and form IV	33, 28	11, 7
V	22	9	Doors and windows grills, gates	4	Form IV and vocational training	18, 30	1, 4
W	23	20	Meat-grilling ovens, charcoal stoves, and gas stoves	4	STD VII and STD VII	36, 25	20, 6
X	24	19	Window and door frames, gate frames, cooking stoves, and railings	3	STD VII and STD VII	28, 25	10, 5

Figure 1. Examples of products produced in studied microenterprises.

Semistructured interviews [36,37] were conducted with two subjects who were familiar with design practices in the firm. One subject was the main speaker and the other was there to corroborate the accounts given by the main speaker and to provide clarifications or any additional information whenever required. As such, a total of 48 subjects participated in interviews. It should be noted that this was qualitative research and the intention was not to gather data or information for statistical analysis. The focus was, rather, on acquiring a proper understanding of the actual design practices through qualitative research. Only 5 of 48 interview participants held bachelor's degrees. All respondents were male, and most of them lacked technical or design training.

Interviews took place at the interviewees' places of work. This allowed the interviewers to informally observe the working practices and culture in informal metalworking microenterprises. The interviewees were asked to refer to particular projects during interviews. Figure 2 shows examples of working practices and conditions in these microenterprises. The mean duration of the actual interviews, excluding briefing and debriefing, was 51 min. We sought consent of the subjects to participate in the study, to audio- and video-record the interviews, to take pictures, and to use gathered data/information in analyses and publications.

Figure 2. Some examples of working practices and conditions in informal metalworking microenterprises.

Interviews in all 24 microenterprises were administered by using the Swahili language and were audio-recorded. The recorded audio contents were then transliterated in Swahili and eventually translated into the English language. A general inductive and iterative approach was then used to analyse the translated transcripts [36]. The analysis was content-driven.

Sections 4 and 5 present the results of the analysis. Excerpts from the transcripts of the interviews are included to illustrate the findings. Some of the excerpts of the interviews have been edited for ease of comprehension and any additional information is included in brackets.

4. Identification of Consumer Needs

There is little knowledge about how informal metalworking microenterprises in developing countries elicit customer needs [38]. In this section, we present findings on how the designers in microenterprises elicit customer needs and how they formulate and organize the requirements—which form the first part of the research questions of this study.

Interviews were conducted in the firms listed in Table 1. Generally, design processes in these informal metalworking microenterprises entailed interacting with clients with a view to gathering their wishes and preferences with respect to functionality, dimensions, material type, aesthetic features, and cost of the product.

4.1. Elicitation of Needs

We explored how the needs of the customers are identified. Elicitation of needs in these microenterprises essentially entails conversion of tacit and subjective customer verbatim constructs into needs statements. Needs and requirements for products in these firms largely originate from interactions and one-on-one conversations with customers, as evidenced by the following sample interview excerpts.

> The client paid visit once to the [our] firm to press order, but we also visited the client to verify the space dimensions [Firm I, movable kiosk] ... I interacted with the client straight away by discussing the picture that he brought and we also paid the visit to the client to take measurements. [Firm M, fence gate]

Some of the requirements originate from existing products. Customers use sketches, engineering drawings, and pictures of existing products to describe how they wish their products to be. Pictures are widely used as stimuli for discussion—refer to the interview excerpts below.

> The client came with pictures of an existing bed frame and we discussed and changed its appearance and added seating feature [Firm K, bed frame] ... After seeing the pictures and based on our personal experiences we recognized the needs [Firm L, gates and window grills] ... the client used the picture to explain how she wanted the dressing table to be like [Firm N, dressing table] ... the client brought a picture of window grill with decoration features he wanted". [Firm X, Window grill]

The designers and their clients refer to the pictures during discussions and agree on additional features to incorporate in the final designs.

For products with novel features, the design processes start from scratch. Some microenterprises use few requirements to produce trial products that they showcase to potential customers. Designers and customers use these trial products as stimuli for discussing how the product should be—see quotes below.

> For this product we developed a [sample] product and interacted with potential clients mostly during exhibitions [to explore its acceptability]. We visited several exhibitions to showcase the prototype. [Firm C, foldable multipurpose furniture]

Some designers visit clients and interview them at their sites—see sample excerpt below. The number of outgoing and incoming for such visits vary from two to ten. This allows the designers to know the use environment of the product.

> The client paid visit once to the (our) firm to press order, but we also visited (the client) to verify the space dimensions. [Firm I, movable kiosk]

The effectiveness of needs elicitation usually depends on the technique adopted and used [39–45]. Informal metalworking microenterprises use unstructured interview methods and appear not to prefer using formal alternative needs elicitation channels such questionnaire surveys, structured interviews, and maintenance reports.

4.2. Interviews with Customers

Interviews with customer is the approach that is widely used to collect needs data in informal metalworking microenterprises. Some researchers claim that interviews—particularly structured—are one of the most effective needs elicitation techniques [39]. Interviews enable the informal metalworking firms to get glimpses into how customers wish the product to function and be—see the representative excerpt below.

> We discussed and agreed with the client on how the gate should be like and how different [the client] wanted it to be compared to the pictured one. [Firm Q, aluminium windows]

Generally, it can be said that the needs originated from interviews with customers, which generated first-hand data that are used in the formulation of requirements. During conversations with clients, firms typically record first-hand needs data by taking notes, sketching concepts, or taking photos, as substantiated by the sample quotation below:

> We took notes [. . .] typically hand-written text complemented with hand sketches to describe concepts. [Firm A, palm oil filter]

However, as demonstrated by the excerpts below, some firms do not document conversations with clients and only just listen and recollect what was said later on.

> . . . . . . we just heard and recalled what the clients had to say. [Firm J, chicken feeding utensil] . . . We didn't sketch anything, . . . we just got word-of-mouth explanations on the needs. [Firm G, Charcoal stoves, barbeque ovens, water gutters, metal suitcases]

Generally, the designers typically receive verbal explanations from clients but do not archive the conversations. They regularly use hand-written text, pictures, or hand-prepared sketches to describe requirements—see the representative excerpts below.

> [Customer came] with the sample photo or sketch. [Firm B, peanut peeling machine] . . . past experiences . . . helped us to identify requirements, and we then prepared sketches of the gate. [Firm T, fence gate]

Traditionally, in order to conduct meaningful needs analysis, it is imperative to properly document conversations. Documentation can be in the form of textual interview transcripts complemented with hand-sketches to record nonverbal information [42].

4.3. Sources of Requirements

In informal metalworking microenterprises, requirements originate from different sources. Apart from interviews, standards and use of past experiences are also the sources of requirements in many microenterprises. Some requirements also originate from design constraints and from the designer's own expert knowledge. Reusing past knowledge and experiences seems to be a natural way to elicit requirements and of handling uncertainties in informal metalworking microenterprises. Moreover, the requirements gathered in informal metalworking microenterprises describe technological, social, environmental, and economic aspects of the product.

4.4. Prioritization of Requirements

Designers in informal metalworking microenterprises identify, at most, eight requirements. The identified requirements describe functionality, appearance, dimensions, and cost of the product, but are generally neither properly worded and documented, nor archived. The requirement statements do not properly describe the product.

Customers are involved in prioritizing the requirements. Apparently, the requirements that describe dimensions, appearance, cost, and functionality of products are given higher priority—see some of the representative excerpts below.

> The appearance and dimensional specifications were given higher priority [Firm N, dressing table]. The strength of materials and dimensional requirements were given higher priority. [Firm W, meat grilling oven]

However, some microenterprises do not prioritise requirements, but give equal priority to all identified requirements.

> All requirements were given equal priorities. [Firm P, windows grill]

In engineering design, requirements are typically prioritized systematically by using formal methods such as Quality Function Deployment (QFD) and Analytic Hierarchy Process (AHP) to help designers set definite goals for their products and to ensure that the design project focuses on and addresses the key customer's needs [39,42,43]. Our findings reveal that the informal metalworking microenterprises did not employ such methods.

4.5. Difficulties Faced in Identifying Needs

Some designers in informal metalworking microenterprises felt that the process of identifying needs is tedious and expensive. Some excerpts from the interviews to explain the difficulty faced are presented below.

> Our approach entailed making prototype and demonstrating concept. . . . was tedious . . . . [expensive], and . . . [lengthy]". [Firm C, foldable multipurpose furniture]

Other difficulties faced include the identification of needs that cannot be met due to limitations of capabilities of manufacturing equipment within the microenterprises, and customers disputing some of the obvious requirements, e.g., those based purely on technology-related and economic reasons—see some of the interview quotations below.

> The customer was [. . .] disputing technical requirements [. . .] wanted the product to be painted without spraying red-oxide paint first to cut cost . . . . [Firm D, door gate]

It was also observed that designers in informal metalworking microenterprises also confront numerous inherent difficulties typically faced in identifying customer needs and requirements. These include ambiguity and imprecision of requirement statements [40], uncertainty of whether needs are genuinely captured [44], and excessive focus on the technical details of a product [41].

5. Conceptual Design

In a formal design process, requirement identification is followed by a conceptual design stage. According to Pahl and Beitz [45]'s model of designing, the conceptual design stage involves creating function structures, identifying working principles, and combining the working principles into a working structure. Additionally, conceptual design focusses on novel idea generation.

Researchers converge on the view that *novelty* is a measure of the newness of a product with respect to existing products in the market satisfying the same function [46]. For instance, the first pin-hole camera, the first X-ray machine, and drugs such as penicillin are regarded as very highly novel products [47].

Industries are under huge pressure to launch novel products because of reasons such as increased competition and customer expectations, rapidly changing technology, and shorter product life cycles [48,49]. To generate novel designs, designers use methods such as brainstorming, biologically inspired design, TRIZ, functional analysis, etc. [50]. Apart from these methods, designers take inspiration from sources such as patents, expert opinions, discussions with colleagues, and past experiences [51,52]. Greater product novelty, in turn, positively influences the product quality, which in turn determines the market share of a product [53–56]. Therefore, in formal design methods, novel idea generation is central to conceptual design.

This contrasts with the informal design process in which the decisions are driven largely by intuition and past experiences. In addition to following informal design processes, the microenterprises interviewed in this study functioned within constrained resources and limited technical proficiency. These factors are likely to influence the design outcomes. Overall, this section, describes the findings on how these firms generate and evaluate alternative product concepts, and how they define product details—which form the second part of the research questions of this study. More specifically, Sections 5.1–5.3 present the findings of our investigation with regard to the conceptual stage of the design process followed in the informal metalworking firms in Tanzania. Section 5.4 focuses on methods adopted by these firms for material selection and determination of dimensions.

5.1. General Approach for Concept Generation

We intended to abstract a general approach to concept generation, which the microenterprises in Tanzania follow. The employees of the firms were asked to brief the steps that they followed after requirement formulation. Sixteen firms responded that they manufactured the product straight away after requirement formulation. Six firms reported generating concept sketches for the purpose of communicating the design to the clients. We present some excerpts from the interview as evidence.

> I started to manufacture the sample product straight away after knowing the requirements and dimensional specifications. [Firm F, Aluminum windows, doors, aluminum-frame furniture]

> We proceeded to take measurements at the site, calculate costs, purchase raw materials and then we started to manufacture the product. [Firm R, Windows, door grills and wardrobes]

Clearly, this contrasts with the formal conceptual design process, which involves activities such as the exploration of concept space, evaluation of generated concepts, creation of prototypes, and a preliminary analysis of the proof of concept.

5.2. Concept Generation

We explored how designers in informal metalworking microenterprises generate concepts. Findings on how they explore and select concepts are presented below.

5.2.1. Exploration of Concepts

To understand whether the concept space was explored, we inquired about the number of alternative concepts generated. Twelve firms reported generating one concept and improvising it over multiple iterations after discussing with the clients. Three firms reported generating four concepts. Two firms reported generating six and nine concepts, respectively. Overall, the majority of the firms generated only one concept. Some excerpts from the interview to substantiate this are presented below.

> There were no any alternative concepts. The client wanted the kiosk to appear and be produced as the one shown in the picture that was provided. [Firm J, Chicken feeding utensils, charcoal stoves, metal suitcases]

> We prepared only one alternative concept and improved by continuously engaging the client" [Firm V, doors and windows grills, gates]

In design creativity research, the number of ideas generated (also known as idea fluency) directly correlates with the quality of ideas [57–60]. Design methods such as brainstorming support idea fluency and are widely used in industries [61]. As most of these firms generated only one concept, it may be unlikely that these concepts would be of high quality.

We intended to understand if the firms had awareness about novelty and innovation. Most firms agreed that innovativeness involves new methods, new designs, the use of new materials, or the use of new technology. It can be inferred that these firms had an understanding that innovativeness involves newness. However, interview results revealed that they did not use scientifically established design methods for novel ideation. They depended on stimuli from social media sites, competitors' products, and discussions with colleagues. Only three firms reported using technical standards, engineering drawing and design methods such as brainstorming. When asked about the use of any special methods to design creative products, they did not report the use of any different methods.

5.2.2. Concept Selection

In a formal design process, designers use the established methods for concept selection. Concept evaluation methods, such as Pugh's method and rank-ordering method, use requirement satisfaction as criteria to evaluate concepts.

In the case of these firms, our observations were the following. Eleven firms reported that the concept was selected based on discussions with the client. Six firms said that concept selection was not required, as they generated only one concept and iterated over it. Two firms seemed to be aware of subfunction concepts and stated that they selected concepts based on discussions with the end users. Here are some related excerpts from the interview.

> For various sub-functions, there were alternative concepts, from which best were selected through discussions that involved both potential end users, and the final composition of the entire product concept was eventually generated. [Firm D, Furniture, doors, shoes-stands, window grills]

> By involving the client (who had the final say) and based on our past experiences. [Firm X, window and door frames, gate frames, cooking stoves, railings]

Furthermore, we intended to understand which product attributes they deemed as important for concept selection. Nine firms said that functionality was the key attribute for selection of concepts, seven firms reported that aesthetics was the key attribute for concept selection, while four firms reported durability as an important attribute.

5.3. Concept Representation

The concepts are represented using various modes, such as by using sketches, clay models, paper models, and CAD models. These representations serve various purposes, such as active learning, refinement, communication, and exploration [62]. From the interviews, it appeared that, in the cases of the interviewed firms, the concepts were represented primarily to communicate the design to the client and to take the approval for manufacturing. Concept representation seemed optional, and the ones that did mostly used hand-drawn sketches as the representation medium. Nine firms said that they manufactured the product directly without representing it, seven firms reported using concept sketches, and one firm reported making CAD models. Related excerpts are presented below.

> We arrived directly at the final solution—based on past experiences. [Firm T, Door and window grills, bed frames, fence gates]

> We directly manufactured the product according to the agreed dimensions and other requirements. [Firm U, Aluminium profiled doors and windows, aluminium furniture, deck rails]

Most firms did not formally document the sketches. Upon request, we collected sketches from three firms only (See Figure 3). It can be seen that the people who prepared most of these sketches lack the skills required for industrial sketching.

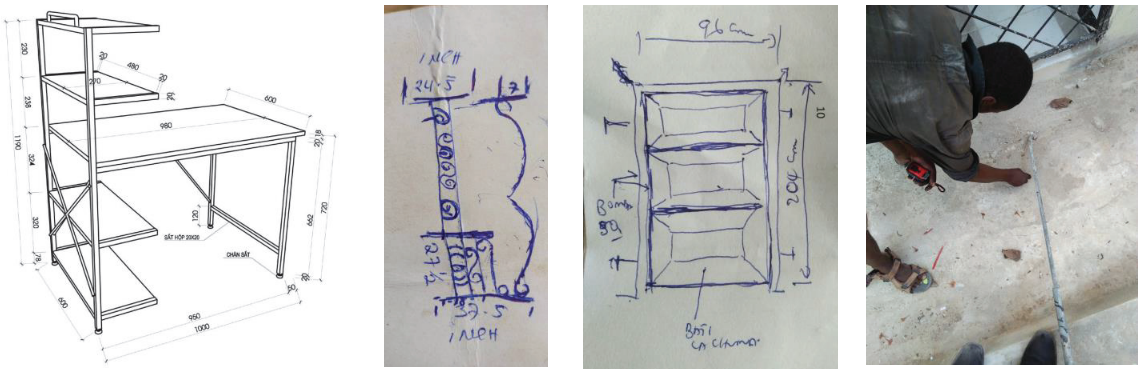

Figure 3. Examples of concept sketches produced by some of the firms interviewed in this study. (a) Firm D manufactures furniture such as chairs, bed frames, doors, shoe stands, and window grills. (b) Firm E manufactures door and window grills and furniture; employee sketching the concept on floor. (c) Firm I manufactures bed frames, door grills, and door gates.

5.4. Material Selection and Dimension Identification

With regard to main considerations for material selection, most firms used square hollow sections of steel and aluminium. Material cost, strength, durability, and availability were found to be the main considerations for material selection. The choice of material was made by the client. With regard to calculation of dimensions, some dimensions were established by visiting the site, while the other dimensions were determined based on past experiences. One firm also reported that they arrived at the dimensions by studying the competitor's product.

In a formal design process, material cost, strength, and availability are some of the governing criteria for material selection. Scientific methods and tools of material selection, such as the Cambridge Engineering Selector (CES) toolkit are widely used for material selection. None of the firms reported using such methods. Similarly, for the calculation of product dimensions, designers used methods such as quality function deployment [62], and referred to anthropometric data [63], industrial standards, and government regulations. However, in our study, only one firm reported using ergonomic standards.

6. Discussion

6.1. Needs Identification

Traditionally, needs elicitation in large formal enterprises is a well-organized process [64–66], which passes through definition of scope, raw data gathering, derivation of needs statements, and arrangement of needs according to their importance.

We explored how designers in informal metalworking microenterprises elicit consumer needs and requirements for products. We found that designers in these firms mainly use interview methods to identify needs and requirements for products. Overall, the designers only use their intuitions to identify the needs and are generally neither unaware of the existence of a formal process for eliciting needs nor of the tools and methods of identification of needs and requirements. Furthermore, we found that needs are not systematically interpreted and translated into requirements. Specifications are not quantified through a formal process that traditionally entails identifying metrics and measurement units, which corresponds with the needs or requirements. Specifications are not necessarily tied to the needs and requirements. The dimensional specifications for the products in these firms are established based on past experiences or by taking actual measurements from the sites. Other specifications are also determined in an ad hoc fashion.

Product specifications are, in fact, the product attributes or design features [67]. Formulation of specifications for a product is one of the mainstream early-stage design tasks, through which concrete specifications are determined based on customer needs [68]. Quality function deployment (QFD) [69] is commonly used to determine the specifications for the products based on the needs. QFD utilizes house of quality (HoQ) to map customer needs and requirements to the specifications [70]. Other methods used include semantics methods [71,72], which apply.

Other identified shortcomings in needs elicitation include (1) the absence of mission statements; (2) assumptions that constrain the development efforts; (3) excessive reliance on the one-on-one interview method, which is known to have inherent drawbacks such as biases and reliance on interviewer capability [33,37]; (4) the absence of needs data that describe sensory experiences, such as comfort or style; and (5) ambiguity in the needs statements.

6.2. Conceptual Design

We explored how informal microenterprises generate and evaluate alternative design concepts and define product details. We found that the number of concepts generated by informal metalworking microenterprises were limited. In most cases, only one concept was generated, which was iterated over multiple cycles of improvement. We propose the following reasons for the generation of a limited number of concepts.

1. In eight cases, the clients brought the photo or the sketch of the final product. In some other cases, clients chose the product from the range of products that had been produced earlier by that firm. So, the firms already knew the product that they had to manufacture. The following excerpts convey this claim. There were no any alternative concepts. The client wanted the kiosk to appear and be produced as the one shown in the picture that was provided. [Firm J, Chicken feeding utensils, charcoal stoves, metal suitcases] Decoration features—the client wanted the bed frame to appear as in the picture. [Firm W, meat grilling ovens, charcoal stoves, gas stoves] The client visited us and selected the product that closely match the envisioned product. [Firm H, Bed frames, door grills, steel gate]
2. In our view, products such as window grills, gates, and metal frames received as orders by these firms are already highly explored by designers. The products that can challenge creative thinking and push the boundaries of technical know-how were usually not received as orders—as can be seen in Table 1. Therefore, these firms might not have felt the need to generate multiple concepts.
3. It appears from the interviews that the clients had the final say in the decision making. It is possible that clients, per se, were biased towards the existing designs and might not have been confident in the new concepts produced by these firms. Thus, this would have stopped these firms from generating new concepts.

Designers use various concept-representation modes, such as paper models, cardboard models, sketches—digital and physical, clay models, and CAD models [62]. For these modes of representation, concept sketches seemed to be the dominant method for concept representation in the case of the interviewed microenterprises. These sketches were informally documented with people who seemingly lacked the skills needed for industrial design sketching. Overall, the limited use of concept-representation methods might be due to lack of proper training and required resources. Further, it might be that the designers had prior experience with the manufactured products, so they did not feel the need to represent these designs in a detailed manner.

While scientifically established design methods such as SCAMPER and brainstorming were not used, the major sources of stimuli that they reported were social media sites, discussions with colleagues, and competitors' products. Again, this indicates a lack of training, awareness, and required skills for a designer.

Functionality and aesthetics seemed to be important product attributes for them. They determined critical dimensions by taking measurements from the use environments of the envisioned products, by using their own past experiences, or by adopting dimensions of the existing products. Overall, materials are selected by the designers, but customers have the final say. The customer also has the final say in deciding on features of the product. Additionally, those surveyed appeared to be familiar with the concepts of novelty and innovation.

Our results corroborate earlier research, such as in [8,29], which reported that informal sectors avoid exploratory activities such as prototyping or tinkering due to costs and available resources. Additionally, researchers have emphasized on the need of co-designing at every phase of design process, especially for sustainable impact on marginalized societies [73]. In our study, we observed that these firms maintained regular interactions with their customers, who seemed to have the final say in the design and manufacturing of the product. This points towards the existence of co-designing practices in the informal sector.

7. Conclusions

This research investigated the design process of the informal microenterprises in Tanzania—in particular, the need identification, requirement formulation, and conceptual design phases of a design process. For this, we interviewed 24 metalworking enterprises at their workplaces in real settings. With regard to need identification and requirement formulation, it was found that these firms follow their intuitions to identify the needs and are generally neither unaware of the existence of a formal process for eliciting needs nor of the tools and methods of identification of needs and requirements. With regard to conceptual design, it was found that concept exploration and ideation methods are not followed. In most cases, they receive routine job orders, for which ideation in not considered to be as important. For both, need identification and conceptual design, these firms rely heavily on the past experiences and in general lack the necessary tools and training.

Additionally, this research has revealed that design activities, e.g., activities associated with needs identification and conceptual design, are influenced by the context in which those activities are performed. For instance, the informal metalworking microenterprises studied in this research face various constraints, such as a lack of formal design education and weak access to various resources. These sociocultural and economic aspects of the context have an influence on their design activities.

A limitation of this work is that the questionnaire used was written in English and translated into the Swahili language. The transcriptions of the responses in the Swahili language were translated into English. It is probable that these translations might have altered the meaning of some words.

This research raises several interesting questions for further research, some of which are discussed below.

1. It was observed that these firms, in most cases, used informal design methods. A better understanding is required on the effectiveness of formal design methods in the constrained environments, such as those in the interviewed firms. This is an interesting and important area for further research, as formal design methods are typically developed to support designers in contexts that are distinctly different from those in which the informal firms operate.
2. Further research can also aim to develop bespoke design methods for these types of firms, taking into account their educational background and the various resources that are available to them. These design methods can also be created with the firms, and then systematically tested to assess their impact on the design outcomes of the firms.
3. The employees in these firms maintained regular interactions with their customers, who seemed to have the final say in the design and manufacturing of the product. Involving customers in designing and manufacturing is a recent practice in industries, which comes under the purview of co-designing. It is unlikely that the employees of these firms, who did not have access to proper training, were aware of "co-design" as a recent practice. This points to something called *tacit co-design*, meaning that these firms unknowingly co-designed products in their own intuitive ways.
4. Most of these firms reported using the Internet through mobile phones only. Furthermore, only a few employees in these informal microenterprises had knowledge

of English. This calls for the necessary development of smartphone-based design methods and training programmes in local languages.

Overall, this research paves the way for a number of future research avenues in terms of developing dedicated design models and methods for constrained environments, studying tacit co-design and development of low-cost design tools in local languages. Also, it is likely that the results from this study hold true for resource-constrained enterprises in other developing countries.

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Designing Sustainable Services for Cities: Adopting a Systemic Perspective in Service Design Experiments

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Abstract: Cities provide a privileged context for observing environmental, social, political, and economic changes. They offer great opportunities for experimentation, often becoming laboratories for innovative practices in different fields of research. This article describes how Service Design can concretely contribute to promoting sustainable and inclusive services at the city level by adopting participatory, collaborative, and multi-stakeholder processes. In particular, the article analyses, through a literature review, the evolution of service design applied to complex and large-scale systems, identifying in the recent conceptualization of service ecosystem design the framework for designing sustainable and inclusive solutions in urban contexts. Two design studios were developed through a collaborative design process to link theory and practice. Three examples of service concepts are described as experiments in transformative service design practices that incorporate systems thinking. The article explains how service designers can deal with complex and large-scale transformations in terms of sustainable urban services and outlines a service design process and some design and research implications related to the ability to adapt to uncertainty and incorporate complexity as design elements.

Keywords: service ecosystem design; transformative service design; sustainable services; services for cities

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1. Introduction

Currently, 80% of global greenhouse gas emissions and 50% of global waste are generated in cities [1]. Furthermore, it is estimated that by 2050, 66% of the world's population will live in urban settings, and much public and private investment in most countries will support this rapid growth [2].

In 2015, the European Commission published the first Circular Economy Action Plan [3] to support sustainable waste management, land use, reuse, and recycling through cocreation strategies between economic actors, politicians, organizations, and citizens. The policy thus includes the strategic and management issue as closely linked to the social one, supporting an integrated, multilevel approach in which people are recognized as active actors. These strategies are then implemented through the European Green Deal, which supports the integration of circularity and sustainability mechanisms in urban contexts in line with the goals of the SDGs (Goal 11 Make cities and human settlements inclusive, safe, resilient and sustainable and Goal 12 Ensure sustainable consumption and growth patterns) that deal with safe, resilient, and sustainable city models. The recent concept of the circular economy is then applied to urban contexts through the circular city, eco-city, and resilient city, which complement the more technological smart-city model. Many European contexts have embraced these principles by explicitly putting them on the political agenda. For example, Helsinki has integrated circular economy guidelines into development policies, supporting design, production, and consumption models based on the regeneration of resources, with a participatory and inclusive approach [4]. Similarly, Amsterdam has implemented a strategy embedding circular processes in the housing sector and the involvement of citizens in numerous initiatives related to recycling and reuse processes at neighborhood level [5]. Milan has developed a resilient strategy to tackle environmental, social, and economic challenges through collaborative actions involving citizens and policy makers.

Transition models towards sustainability [6] also pay more attention to people as knowledge agents able to support transformation processes towards more sustainable, resilient, and inclusive cities by unleashing their creative potential and adopting collaborative and participatory strategies to improve quality of life and well-being [7]. In recent years, the European Commission has played an essential role in supporting sustainable transition, calling for an increasing involvement of people in development processes. A model called the "human-centered city" has been proposed: "Citizens become city-makers and shapers, architects and cocreators of their own evolving urban development" [8] (pp. 12–13), going beyond technology or market-led models and considering participation, codesign, and cocreation as enablers of innovation. Consequently, emphasis is placed on needs, expectations, and lifestyles as elements around which innovation strategies can be developed. Citizens are thus seen as active parts of the system and not only as recipients of top-down decision-making processes. The New European Bauhaus initiative, linked to the European Green Deal [9], is a recent example of how these issues are at the center of the EU policy agenda. The initiative aims to support more robust connections between theoretical frameworks and practical initiatives in different local contexts, where the connections between different actors and competences becomes crucial.

Cities are considered creative laboratories [8] where the great potential of research, knowledge, and skills can foster innovation processes. The design (and redesign) of urban services to meet the renewed needs of citizens, organizations, and institutions towards more sustainable and inclusive scenarios is at the center of the international debate and local policy agenda. For service designers, this implies having a major role in societal change and managing complex systems and long-term and large-scale changes, and interacting with various actors who with different roles influence and participate in the decision-making and design process. This scenario highlights the need to move from the individual and the one-to-one relationship between provider and user to a systemic and large-scale vision with transformative impact [10–13].

This article discusses the implications for service design of sustainable solutions and collaborative and multistakeholder processes at the city scale, adopting the service ecosystem design perspective conceptualized by Josina Vink et al. [14]. Services are one of the critical infrastructures of contemporary society, and urban contexts are a privileged arena in which to experiment with service design by adopting a systemic, collaborative, and large-scale perspective, supporting the disciplinary advancement towards greater integration of complexity as an element that connotes both conceptual frameworks and practices [15–17].

Contemporary cities are increasingly adopting collaborative, participatory, experimental, and innovative governance models [18] that involve the ability to coordinate different actors around shared goals. As far as service design is concerned, the human-centered approach and codesign and cocreation processes facilitate and enable the construction of consensus relationships and help to visualize (including through experimental prototypes) solutions, validate their effectiveness, and imagine their feasibility. In these design processes, communities play a crucial role in promoting and accompanying innovation at the local level [19,20] concerning infrastructures that can reduce the gap between the political class and citizens.

This article aims to contribute to the debate on the evolution of service design in its transformative role applied to large-scale and inclusive sustainable urban service design, adopting a service ecosystem perspective. Due to the relatively recent theorizing on these issues, how theoretical principles can be applied in service design practice and how processes and tools can be revised remain underexplored.

What conceptual and operational revisions are needed when service design deals with the urban scale and sustainable issues, that is, when the design object is a complex, multi-actor system with long-term development?

To better describe the research path adopted, the following sections are structured as follows:

1. Section 2 describes the objectives, design methodology, and tools adopted to support the overall research path.
2. Section 3 focuses on the literature review.
3. Section 4 describes the design studios process and illustrates three service concepts that emerged.
4. Section 5 provides a discussion of the results.
5. Section 6 identifies limitations and directions for future research.

2. Materials and Methods

This article reflects on the importance and necessity of adopting a systemic and collaborative approach to service design when dealing with complex issues and contexts. By adopting the theoretical framework of service ecosystem design, two areas of design research and development are outlined that imply an implicit relationship with the uncertainty of the design outcome and the complexity of both the design object and the service design itself [14]. Furthermore, a design process is outlined that incorporates systemic, multilevel, multi-actor elements.

The research followed a research-through-design process. First, a literature review was conducted on publications indexed in Scopus and Google Scholar (from February and March 2022 and updated as of September 2022), which led to defining the state of the art of the scientific literature on sustainable service design and service design about urban systems. The review revealed, on the one hand, the need to update service design processes and tools to move beyond linear models to more circular and relational ones and on the other hand, the need to develop and better integrate collaborative practices in which value is cocreated in different circumstances and contexts [14,21]. The theoretical phase led to the identification of the concept of service ecosystem design as a conceptual reference for the application of service design in complex systems. The research was linked to two design studios developed at the Design School of Politecnico di Milano to reflect on the theoretical model through practical action. The courses, entitled Design for Better Futures, aimed to generate service concepts capable of creating value for urban contexts, focusing on issues of sustainability and inclusiveness. The studios were conceived as experimental processes incorporating systemic and complex dimensions, involving many actors able to contribute with different roles and in different phases through collaborative and reflexive processes.

3. Literature Review

3.1. Sustainable Services and Service Design

In the design field, the relationship with sustainability, the systemic perspective, and the large scale have been explored from different angles. Ceschin and Gaziulusoy [22] describe how the concept of design for sustainability has evolved by shifting the focus from product innovation to the product–service, social innovation, and socio-technical systems. This evolution implies a shift in the focus of design from the material to the immaterial, towards solutions that address social, economic, political, and environmental problems, considering design as a competence that can contribute to the transition towards a resilient, equitable, and sustainable society [23,24]. Issues related to the large-scale, systemic perspective have been explored through the concepts of systemic design [25], transition design [26,27], transformation design [12], Design X [28], and design for social innovation [29–31] including related to the enhancement of territories and communities [32,33]. All these models emphasize how design is increasingly moving around social changes and emerging values in environment and culture, in the connection between local and global scales, and through new relational models between stakeholders.

As far as services are concerned, the exploration of systemic and large-scale changes is related to the activity that Ostrom et al. [34] propose as "leveraging service design", i.e., the investigation of crucial societal problems [15]. Service design is described as a holistic, collaborative, and human-centered approach that includes strategic aspects [35–38]. Sangiorgi [16] identifies three areas for service design evolution: interactions, complexity and transformation. From this perspective, service design as a strategic approach is applied to urban contexts by incorporating the complexity of sustainable transitions [39], including organizational, social, and technological aspects, along with qualitative components concerning users' needs and how they interact with providers and their context [40]. The adoption of design approaches to support sustainable societal development [22,29,41] entails the recognition of systemic and complex dimensions, the transformative capacity of long-term outcomes, and the importance of connecting and involving different actors in the design process [42], strengthening what Irwin refers to as the "connective tissue" [41].

In recent years, the integration of service design research and practice and codesign processes with systemic aspects of sustainable transition on an urban and territorial scale has been investigated from different perspectives [43,44]. Research initiatives are contributing to the advancement of knowledge by exploring the role of design in large-scale sustainable transformations. Examples include projects such as Reflow (https://reflowproject.eu/about (accessed on 12 October 2022)), which explores how cocreation can contribute to circularity at the city level; Retrace (https://projects2014-2020.interregeurope.eu/retrace (accessed on 12 October 2022)), which aims to investigate the link between systemic design and urban policies; and NetZeroCities (https://netzerocities.eu (accessed on 12 October 2022)), focused on achieving climate neutrality for cities through a broad participatory process. On a practical level, some experiments have been proposed by service design agencies, such as Snook or Koos that have created specific tools to promote circularity at the urban scale from a service design perspective. However, there is a need to revisit the processes and tools according to the broader design focuses, application scales, and timeframes. In general, the explicit contribution of service design in sustainable city transition processes is still under-explored, and the role of service designers within large-scale transformations remains marginal, underrated, or confined only to the execution phases.

3.2. Service Ecosystem Perspective

The concept of a service ecosystem is related to the discipline of marketing concerning the issue of value creation through a multi-actor process [45]. From the service logic perspective, the service ecosystem concept describes a system of interacting actors who cocreate value and share norms, rules, and practices [46–49]. The concept of service ecosystem is adopted in management and marketing to describe value creation models in service innovation and design processes. Recently, service ecosystem design has been conceptualized [14,50] providing a comprehensive understanding of service design and opening new research and experimentation opportunities. It emerges as an evolution of the service design concept and then design for service [14]. The approach implies the consideration of updating service design and its design object by acting on different scales and linking the micro, meso, and macro levels of the system in which it operates [46,51], integrating a system thinking dimension [52]. Therefore, the service ecosystem perspective is related to the design of complex systems in which the transformative aspect becomes significant [11,13]. Vink et al. [14] identify four constitutive elements of service ecosystem design that refer to (i) the purpose (why), described as the facilitation of the emergence of desired forms of value cocreation; (ii) to materials (what), such as institutional arrangements and their physical implementations; (iii) to processes (how), such as how to incorporate feedback loops of reflexivity and reinforcement; and (iv) to actors (who), such as the collaborative design by all actors. These elements will guide the reflections within the teaching process described below.

4. Service Design Studios Process and Tools

The design studios involved in the research process are part of the master's degree in Product Service System Design at Politecnico di Milano. They aimed to lead students through a service design course that simulates a real-life experience and enhances the participants' critical and reflective research and design skills. They developed over four months.

The studios considered for this research were developed in academic years 2018/2019 and 2020/2021. They involved four lecturers: an academic expert in service design and innovation, an academic expert in business and social entrepreneurship, a professional designer expert in service prototyping, and a professional expert in new technologies. About 40 students per academic year participated in the courses.

The didactic programs were linked to the urban context through direct contact with local stakeholders (i.e., municipalities, public and private organizations, local authorities, and citizens) who were actively involved in the service's research, design, and validation phases. In addition, experts were invited to provide specific thematic contributions, such as on ethnographic research, social innovation, sustainability, and circular economy.

The studios were structured according to iterative research–idea–verification procedures lasting four months each year. In particular, the macro phases were as follows: (1) understanding the context and problem farming; (2) the creation of project scenarios; (3) service concept; (4) idea evaluation; (5) idea refinement; (6) service development; and (7) service simulation and feedback (see Figure 1).

(1) Understanding the context and problem farming is the phase in which the systemic and multi-actor dimension of the urban context is analyzed and understood. In addition, research gaps, i.e., potential areas for project intervention, are identified. This phase is characterized by desk research activities (e.g., policy reports, city data, academic articles, consultancy reports, case studies) and interviews with citizens, city experts, key people, and practitioners. The outputs are related to the descriptions of the local resource system, the macro-drivers that will guide urban transformations, and the design opportunities to be better explored in the subsequent phases.

(2) Crafting design scenarios outlines a long-term vision of urban development regarding sustainability and inclusiveness. Design areas are explored and described through the definition of a long-term design vision (scenario). Design questions are then formulated from the knowledge and data acquired (i.e., what if or how might we questions). The outcomes are design directions—speculative in nature—that are integrated with the research data and are intended to guide the generative phases. The scenarios are then validated through face-to-face interviews with citizens (possible end-users) and with professionals and policymakers to identify promising development paths, as well as potential barriers and constraints.

(3) Service ideation is the phase linking the theoretical part to the design part, identifying a potential solution, and outlining the service ecosystem and the system of actors connected to it to analyze their needs and behaviors. In this phase, the elements contributing to the value creation process are outlined, together with the service-specific aspects such as the offerings, interactions, and touchpoints.

(4) Idea validation comprises an additional desk research and case study analysis phase together with a validation process of a qualitative nature carried out through expert interviews, codesign workshops, and early-stage prototypes. This phase represents the first feedback loop concerning solutions by initiating a collective design process with users and stakeholders.

(5) Idea refinement is the phase in which service ideas are further refined through a second feedback loop. Refinement takes place through interviews with service actors, sector experts, and users involved in codesign workshops aimed at improving the qualities and processes of the solution coherently with the identified scenario and the principles outlined in the initial phase.

(6) Idea development is the moment in which the service concept is developed in all its parts through mapping the interactions of actors and resources, the offer system, the

business or social model, and the various journeys, and touchpoints. In this phase, the service is prototyped in the user experience parts and touchpoint components (i.e., through experience prototyping or video prototyping). At the same time, from the users' perspective, the study of the interactions between stakeholders and the user journeys of the service is supported by a business model that considers the value cocreation process [53], the market analysis, and the study of potential competitors.

(7) Service simulation and feedback refer to the moment in which the service is presented and discussed with a selection of users and actors potentially involved in the solution and stakeholders that could facilitate or inhibit the process, or, in other cases, the identification of real development potential identifying possible partnerships and collaborations, potential conflicts in the system, opportunities to obtain resources, and obstacles.

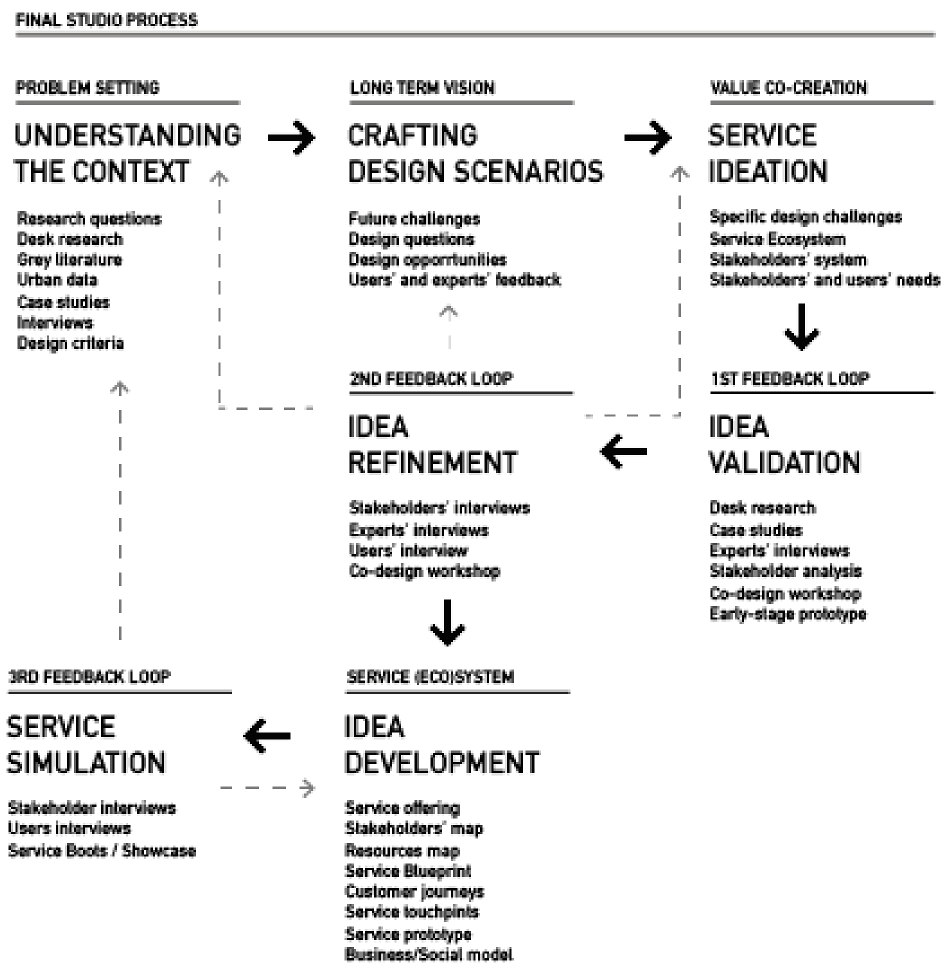

Figure 1. The studio design process.

On the one hand, continuous iteration and experimentation allowed the projects to evolve through ongoing testing to focus more specifically on the forms of value cocreation, the ways in which the service actors interact, and their role in the process from conception to implementation. On the other hand, they helped the students to metabolize what is required outside the university course, which Aksoy et al. [54] identify as the ability to include potential obstacles in the process, the ability to deal with complex situations, and the ability to involve different stakeholders collaboratively. In particular, the initial stages supported the creation of shared visions and values among stakeholders. The final stages aimed to strengthen the relationships created in the previous ones to identify new forms of collaboration between different stakeholders. Throughout the journey, end users played an active role in the value creation. The service concept ideation fostered and accelerated the dialogue between the various actors sharing a common vision on integrating sustainability and inclusion in decision-making and operational choices. In addition, the stakeholders involved reflected on how to adopt a people-centered perspective, understanding the importance of relationships, processes, practices, and tools characterizing the service system rather than designing a single solution.

Three service ideas developing different themes are described below, starting from the common frame of reference.

4.1. Promote the Culture of Reuse of Building Materials

The Renova service concept aims to reduce waste from demolition or renovation to feed a reuse circuit for building materials. The idea is that of a service based on the recovery and resale of building materials in good condition that would otherwise once decommissioned become waste. This is made possible by the active involvement of private contractors, construction companies, and deconstruction companies. The model seeks to overcome the linear "take-make-reject" model by proposing a circular approach capable of creating value for end users and the territory and reducing resource consumption and the economic impacts of disposal (long-term scenario). The final solution, referring to the Brazilian context, is a digital platform where end users (i.e., architects, designers, and citizens) have access to a catalogue of used materials in good condition that can be reused in other contexts. In addition, the platform offers—through augmented reality—the possibility of virtually positioning elements in 3D models to facilitate the appropriate choice of materials and finishes through an interactive and empathic process. The circular process, therefore, connects different actors within a virtuous path of recovery and reuse of materials. It on the one hand generates less consumption of resources and an efficient process and on the other hand reduces the production of construction waste, management, and disposal costs with a consequent positive impact on the territory. This process implies coordination and collaboration between public and private actors, changing existing processes. The advantage for construction companies is the reduced waste load and considerable cost savings for end users. The solution, therefore, combines aspects related to the user experience (micro level), the relationship between companies, local authorities, and municipalities (meso level) and the link with waste management and recovery policies on an urban scale (macro level). The solution was developed through an in-depth study of the Brazilian context and discussions with local architectural firms and potential users. The service concept, therefore, starts from developing knowledge of how the actors in the system interact today, and from providing a vision of how their relationships could change the development and adoption of new processes and tools for the actors involved.

4.2. Promote the Culture of Reparation among Citizens

Waste disposal is one of the crucial issues to act on to support sustainable processes in the urban environment. StoryGood is a platform that helps citizens maintain and manage their electronic devices to reduce their early disposal. The idea of the service is based on enabling citizens to consciously manage the use and maintenance of their electronic devices by accessing a digital repository that gives access to information on the life cycle of products (service design long-term view). The service is developed through a digital platform through which users are provided with a series of information, together with guidelines and tutorials on how to repair their devices independently or by turning to specialized centers in the city. Users are then in touch with specialized centers spread throughout the city, following the model of repair cafes.

The idea of the service is that products displayed on the platform will be classified according to the sustainability of the production process, durability, energy consumption, and ease of repair. This information will be obtained through data collection from company reports, repair center evaluations and end-user feedback (stakeholder relations). In addition, the community system generates a reward mechanism for users who make the community of good practices visible at city level, supporting conscious consumption and the consequent reduction of electrical waste. The idea is that end-users can be empowered to adopt sustainable consumption behavior, saving money, and helping to reduce CO_2 emissions. The repair centers also become neighborhood hubs that on the one hand support the spread of circular models and on the other hand strengthen the connection between citizens by fostering the emergence of new local networks. The expected long-term result is that companies are incentivized to produce easily repairable products, involving users to motivate a repair culture, thereby discouraging premature disposal.

In this case, the concept of sustainable service can be described as the ability to promote sustainable behavior of a system of actors through the creation of different business models (local hubs) and favoring virtuous cycles on a large scale, strengthening social capital, and supporting sustainable growth and development. Here again, the final solution stems from direct dialogue with the system's potential stakeholders and reflection on how different players can participate in the creation of value for the local context through new forms of relationships between citizens, businesses, and public administrations.

4.3. Promoting the Social Inclusion of Elderly People

The NET service concept falls into the area of sustainability mainly related to social innovation. In particular, the service concept focuses on including fragile groups in using digital services and, therefore, on the need to foster learning processes of digital tools and devices. At the same time, it enables communities to maintain and strengthen social ties. On the one hand, municipalities support smart city concepts in which technologies are fully embedded in everyday life; on the other hand, a segment of the population remains marginalized with the consequent difficulty in accessing public services and, to some extent, being restricted in exercising their rights. NET's purpose is to support people's learning processes using technologies and technological devices, through practical courses (online and face-to-face experiences) in which experts and professionals share their skills through informal and experimental approaches. In particular, face-to-face experiences are designed to be implemented in significant places in the neighborhood (e.g., shops, bookshops, cafés) to foster social relations and create new mutual aid networks (stakeholder involvement). The idea is based on the concept of proposing peer-to-peer learning paths that support citizens' creative abilities and participative attitude (enabling skills), integrating the use of technology in everyday life. In this case, conceiving sustainability for its inclusive value capable of generating social capital is a matter of envisioning sustainability. The service idea considers the users' needs and the local capacity to respond to demands by interacting with neighborhood structures. It also proposes a scenario where micro-scale solutions can be replicated and adapted to other neighborhoods (service impact). It is also a matter of identifying the appropriate resources and locations on an urban scale to ensure the evolution of the system and its impact on citizens. Based on the city context of Milan, the service also links with the municipality's training and inclusion initiatives, thus building a link between the service, local policies and public services.

5. Discussion

The perspective of ecosystem design proposed by Vink et al. [14] outlines an iterative process based on continuous experimentation and prototyping in which functional aspects are complemented by the quality of interactions and the quality of touchpoints that determine how actors interact with the elements of the system and with each other. It means imagining new ways of cocreating value for the service ecosystem [55] by redefining connections, integrating resources, and enabling the capabilities of people and organizations. In other words, the holistic, collaborative, and human-centered approach to service design can support the creation of new value propositions through the observation and understanding of users' behaviors and needs and the links between the actors involved, anticipating future development trajectories [56].

The solutions that emerged from the educational experiments emphasize the importance of designing sustainable services in an ecosystemic perspective. The service solution is not the result of a single action but is cocreated by a community of actors contributing to the generation of value. Indeed, to imagine real impacts in terms of sustainability, it is necessary to think about the ecosystem of actors that will make the service sustainable, contribute to its formalization, support the creation of the local network, and enable the connection with the policy system. From a service design perspective, this implies considering pathways beyond the single user experience, including a broader perspective that encompasses a broad community's tensions, conflicts, values, and needs and the ability to build long-term visions and bonds of trust. [57]. As Vink et al. [14] pointed out, this implies an assumption of unpredictability due to contextual emergencies and the complexity of social interactions.

Designing sustainable solutions also implies the definition of new service ecosystems. In the experiences presented, solutions mean the creation of new local systems, in which people, organizations, and institutions actively participate, in some cases reviewing or updating their roles within the service system (as in the example of collaboration between demolition companies, municipalities, and design firms in the case of Renova). Another element that enters the design process is the impact the solution can have at the micro, meso, and macro levels in a vision of long-term growth and development. In the initial stages, it is then necessary to consider the ability to influence other contexts, generate awareness and identify potential barriers to the creation of new bonds, to behavioral change, to fostering sustainable attitudes.

5.1. Sustainable Service Design as Adaptation to Complex Systems and Systemic Design

The transition to sustainability (of products, services, processes, systems) requires the ability to address changes that need investments of time and resources. These changes must be observed from a systemic perspective that includes the connection between large and small scales and the understanding of macro-systems and the personal sphere related to people's needs and behavior. Manzini and Rizzo [58], using the lens of participatory design, emphasize the importance of adopting a systemic perspective. They describe large-scale transformation processes of social innovation as the result of a series of actions carried out at the local level that are then amplified, coordinated, and systematized on a larger scale by different actors and competences. Therefore, the design of sustainable services inherently implies a systemic approach to design [59], which becomes essential when the design object is the city.

As recognized by Nie et al. [60] designing—taking into account ecosystem relationships and implications—involves considering interrelated levels of design. The micro level concerns the user's interaction with products and services. The meso level is the relationship between the different organizations that are part of the system, while the macro level implies a relationship with national strategies and policies. These levels have been integrated from the initial stages of the design process, starting with the research, to the final stages. Indeed, the results are based on the recognition of the different needs of service users and public administration, the analysis of evidence and trends, and the data collection. The solutions outlined include the ability of organizations and individuals to participate with an active role in the delivery and maintenance of services, creating the connections for their development.

Designers are increasingly called upon to "work more and more with activities that have mostly social implications" [61] (p. S886). This implies a reflection on how design practice can and must evolve to respond to emerging needs also linked to the rapidity with which socioeconomic and political contexts grow. Given the relational nature of the process, it is also essential to strengthen an empathic component [62] that puts people's needs, values, and behavior at the center, as well as relationships in the long term.

Acting on a large scale and through a systemic lens requires a redefinition of service design process and tools to integrate this complexity into research, design, and implementation processes. This has taken place, for example, in the context of participatory design [58,63] and design for sustainability [22], by evolving the design object from the product to socio-technical systems, which Binder et al. [64] define as *things*, i.e., the transition from a single solution to socio-material assemblages of humans and artefacts. The possibility of transforming such systems is linked to socially driven processes in which service design can contribute to more sustainable and resilient service ecosystems [65]. Integrating such complexity involves shifting the focus from single relationships to more complex relationships between different actors, rethinking the relationship with institutions and designing new service systems [11,66].

Finally, from the perspective of service ecosystem design [14], it is helpful to reflect on how value cocreation can include a more than human component. A further design and research contribution in support of sustainable city-level services can be explored through the non-human elements of the system [67,68] to understand how these may (or may not) influence decision-making and the service system. This entails a review of the approach and an updating of design tools and training processes. This process leads to consider an evolution of the profile of the service designer, who becomes a designer of sustainable service ecosystems, integrating a plurality of processes and competences [14].

5.2. Designing Sustainable Services as an Adaptation to Uncertainty and Unpredictability

Design, by its nature, is a future-oriented approach [69,70], and it aims to resolve the most challenging problems that require designers to have a holistic mindset [27] and the ability to manage the human-centered dimension and multi-stakeholder design processes. The transformative perspective of service design [13–16] entails envisioning collaborative actions on a larger scale where everyone can design [30], where the object of design shifts from product to service, to organizational level, to social transformation [25,71]. In this collaborative transformation scenario, imagining the future could help citizens, organizations and institutions reflect on complex challenges and long-term perspectives to inform the current situation [72,73].

The ability to create design scenarios that enable and guide visions is crucial for the quality of transformation processes [29] and to promote citizen participation in imagining positive futures [13]. Therefore, it is necessary to encourage collective and long-term actions to promote sustainable solutions that guide urban transformations [74]. From a design perspective, this implies considering how change and transformation can be sustained by reforming institutions, institutionalizing change [14], and designing processes adopted by stakeholders to influence the transformation process [75] intentionally.

Considering service design as a collective agent to imagine future trajectories of action for a better society [66,76], it is advantageous to integrate speculative and critical skills and tools within service design practice to enrich the design perspective and address the complexity required by large-scale actions. In this scenario, service designers can support a sustainable transition by enabling collective and collaborative processes through which they identify participatory development trajectories, stimulate conversations, and promote strategic relationships between different actors. For instance, it is about designing creative ways to empower customers and encourage decision makers [77], enabling them to be more aware of their potential as agents of transformation. Therefore, the role of service designers expands, playing a role as a mediator of relationships between public and private organizations, as a director to orchestrate processes and as a facilitator of codesign processes [78], also becoming a co-researcher, a co-problem solver, and a co-agent of change [79]. In this framework, designers work in network structures that cannot be fully controlled but enabled or directed [80]. Designers act as facilitators of a broader "design community" that actively participates in the design process [81], promoting creative ways of dealing with complex, systemic problems in which solutions emerge. It is not only a matter of envisaging how the service will be delivered and how to support sustainable and inclusive processes and behaviors. It is also about designing the enabling conditions (i.e., relationships, tools, practices, activities) for the stakeholders to play a proactive and positive role in the system and to share the same development scenario. The adoption of speculative approaches in service design [82,83] can foster a common understanding of the impacts that systemic transformation entails (or could entail), to reflect on how to measure, over a given period, the repercussions that the service system (and the solutions) has in terms of environmental, social, and economic sustainability. Anticipation capacity can support the creation of new scenarios for cocreating value between networks in complex service systems [84] and investigating which relationships and processes may favor or hinder the transition towards sustainability.

6. Concluding Remarks

This study provides a conceptual and practical answer to questions on how service design can be adopted to promote sustainability at the city level. It proposes a reflection on integrating city transformation and systems thinking into service design. Service design is considered in its transformative capacity from a long-term perspective to creating more sustainable and inclusive cities. This perspective fits into the classification that Banerjee [85] proposes as the design of large-scale system transformation. The scholar states: "the process needs to create cocreative space that engage members and innovators from different disciplines and agencies from various vertical echelons, to look for scaled, multi-objective paradigms and to build in effective ways of implementing at scale" (p. 84). The design studios were structured as cocreative spaces embedding this complexity, including that of the design object and the service design process. The solutions emerged reflect the approach given, also incorporating the actors' intentionality of long-term transformation as emphasized by Vink et al. [14] in the conceptualization of service ecosystem design.

In this framework, service designers were required to be able to build an idea of a possible future and to generate a shared vision in a negotiation process between different actors. Morelli et al. [86] describe four service design capabilities in this scenario: vision building, modeling, working at different level of abstraction, and addressing the context. These are described as the ability to define possible futures and evaluate change, also related to its operational aspects; to identify the levels of intervention from micro to macro, and the ability to analyze the context, grasping its complexity linked to technical, economic, social, and environmental factors. To these, it is necessary to integrate the ability to act in uncertainty and to visualize complexity and shape it by including relationships, times, scales, and different dimensions. An abductive and steering capacity is therefore increasingly required in which the solution is not often the definitive one. When dealing with system transformations, designers need to be aware of the limits that managing complexity and uncertainty entail and face the discomfort of designing the invisible [87]. Consequently, further reflection on the capabilities of service designers in this specific area is needed also drawing on social theories [88], as well as additional validation cycles to update the operational tools and the cocreation process.

The service solutions proposed refer to didactic courses and, therefore, carry with them the limitations of a design simulation, which does not allow the evaluation of the real impact on the city context and the transformations of the system to which the solutions refer. However, limitations relate to assessing how the service ecosystem changes during the design process and what enablers and barriers support or inhibit service delivery need to be considered.

This study raised some questions requiring further investigation into how to integrate systemic perspectives into service design to collect evidence on service design contributions to collective action and on the impact that solutions will have in the city. How can service designers assess and monitor changes and adaptations in the ecosystem? How can long-term change in the complex service systems be evaluated? How might service designers' competences and tools evolve from designing solutions to designing enabling platforms of relationships? These questions emphasize the need to continue action research. Researchers, citizens, experts, organizations, companies, policy makers, and designers must be actively involved in prototyping solutions to promote real transformative impacts through cocreation and codesign processes in a long-term perspective.

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Article

Supporting the Development of Gendered Energy Innovations for Informal Urban Settlements: GENS Codesign Toolkit for Multistakeholder Collaboration

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Abstract: There is still little knowledge about the link between gender mainstreaming and energy security in informal urban settlements and there is limited design support to address this linkage. This paper presents the development and evaluation of the Gender for Energy Security (GENS) codesign toolkit, which was made to facilitate the design of gendered energy innovations for informal urban settlements. The toolkit was developed by applying the Design Research Methodology (DRM) and is grounded in the findings of a literature review, semi-structured interviews and ethnographic fieldwork in two informal urban settlements. The toolkit aimed to support codesign processes by providing its users with knowledge about the gendered energy scene in informal urban settlements and facilitating idea generation for gendered urban energy innovations. The evaluation of the GENS codesign toolkit was conducted during a one-day multistakeholder codesign workshop in Nairobi, Kenya. During the testing, we found that the toolkit was successful in facilitating energetic discussions, helping its users to learn about the gender–energy nexus in informal urban settlements and generate original ideas for gendered energy innovations. The toolkit is an addition to the current tools, handbooks and manuals on mainstreaming gender in the energy sector, with a unique focus on informal urban settlements and supporting idea generation.

Keywords: gender mainstreaming; energy security; urban households; informal settlements; design toolkit; codesign

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1. Introduction

Low-income areas in the Global South are disproportionally affected by energy insecurity [1,2]. This means that they lack the provision of sufficient energy required to meet the basic needs of their households' daily lives with minimal disruptions to supply and at an affordable price [3,4]. There is an increasing interest in understanding how energy poverty in low-income areas is affected by different social inequalities, including gender [5–7]. Lack of energy access is hindering gender equity and the empowerment of women [8]. For example, women and girls suffer from health problems associated with indoor cooking air pollution due to the use of smoke-emitting paraffin and biomass [9]; are often responsible for carrying out the time-consuming activity of fuel collection [10], and thus, drastically limiting the time that could be spent on education and income generation [11]; and are often responsible for ensuring reliable and continuous availability of energy in households [12], which also leads to the associated problems of handling low-quality unsafe energy devices [13,14].

For these reasons, it is crucial to consider gender at the core of energy interventions in order to avoid inequalities regarding aspects such as resources and income, as well as gender roles and responsibilities [15]. Thus, gender mainstreaming, which is defined as "*the promotion of gender equality through its systematic integration into all systems and structures, into all policies, processes, and procedures, into the organization and its culture, into ways of seeing and doing*" [16], must be pursued in order to allow both women and men to benefit from energy access [17].

However, despite the growing body of work on the gender–energy nexus, it must be highlighted that the focus is still limited to rural areas e.g., [8,18,19], while only a handful of studies explore how gender inequalities in informal urban settlements aggravate energy insecurity [20,21]. As pointed out by Musango et al. [5], energy insecurity is also affecting urban poor environments. In addition, in these environments, energy insecurity and unmet energy needs are aggravated by gender inequalities [22].

As a result, a potentially effective strategy to address this problem is to equip energy companies with knowledge and know-how on gender mainstreaming. In this respect, there are many design supports (toolkits, handbooks and manuals) that have been published to guide those seeking to develop energy solutions with gender mainstreaming in mind. However, existing supports are characterised by a lack of focus on informal urban settlements; a lack of focus on idea generation (or codesign) combining gender, energy and informal urban settlements; and a lack of practical applicability due to their extended length and/or required time-consuming preparations. This is confirmed by the interviews we carried out with 15 private companies operating in the sub-Saharan Africa energy sector [23], which showed that none of these companies had used or are using existing gender–energy nexus supports in their practice.

For these reasons, there is thus a clear gap that needs to be addressed: the absence of applicable and effective toolkits supporting idea generation for gendered energy innovations in informal urban settlements. We addressed this gap by developing and testing the first version of the Gender for Energy Security (GENS) codesign toolkit, which is a set of tools that were designed to equip private and public stakeholders for creating gendered energy solutions for informal urban settlements. This paper introduces this toolkit and discusses the results from the toolkit's empirical application with the target users. We developed the toolkit to be used as a knowledge source, as well as an instrument for idea generation. Therefore, the aim of the GENS codesign toolkit is to enable energy companies and other stakeholders along the energy value chain to (1) learn about energy-related practices, issues and existing solutions for female and male energy users in informal urban settlements, and (2) generate ideas for energy solutions for informal urban settlements considering different issues, needs and capabilities of women and men. It must be highlighted that the toolkit targets those energy companies/organisations who focus on solutions to domestic energy needs (e.g., cooking, lighting, water heating, refrigeration, space cooling, space heating, washing and tool powering) and productive use of energy to support small entrepreneurship.

The GENS codesign toolkit was developed by the researchers from the Africa-UK Trilateral Research Project GENS (Gender for Energy Security). The project's overall aim is to enhance the development of energy innovations that consider the different roles, responsibilities and needs of female and male energy users in African informal urban environments [5]. The final goal of the GENS project is to establish Living Labs in the GENS case study locations: Mathare (Nairobi, Kenya) and Groenheuwel (Paarl, South Africa) informal settlements. At GENS, we define a living lab as "*a research and innovation concept for experimental and experiential learning in real-life environment, involving users and multiple private and public stakeholders, aimed at tackling the problem of energy insecurity in urban poor environments*" [24]. The GENS Living Labs are stakeholder-driven spaces for learning about gender roles in energy-related activities; co-creating, testing and observing energy innovations; and scaling up these innovations towards improved gender mainstreaming in the energy sector [24]. We developed the GENS codesign toolkit with the GENS Living Labs in mind as fundamental support that facilitates multistakeholder interaction throughout the above-listed learning, cocreation and implementation stages, taking place within and outside a living lab. However, the toolkit is also meant to be used outside these living lab environments.

The paper is structured into six sections. The next section outlines the methodology used to develop the GENS codesign toolkit and its application process. Section 3 introduces all tools included in the toolkit and the proposed codesign process associated with the toolkit. Section 4 describes the toolkit's testing during the multistakeholder codesign workshop. Section 5 discusses the findings and summarises improvements to be implemented in the next version of the toolkit. Section 6 concludes the paper.

2. Methodology: The Development and Evaluation of the GENS Codesign Toolkit

This section outlines the information collected to develop the contents of the toolkit and defines its application process and testing. Research activities were planned according to the Design Research Methodology (DRM), which is a framework for developing design supports [25]. Our research activities in relation to the DRM stages are described below. These activities are also summarised in Figure 1.

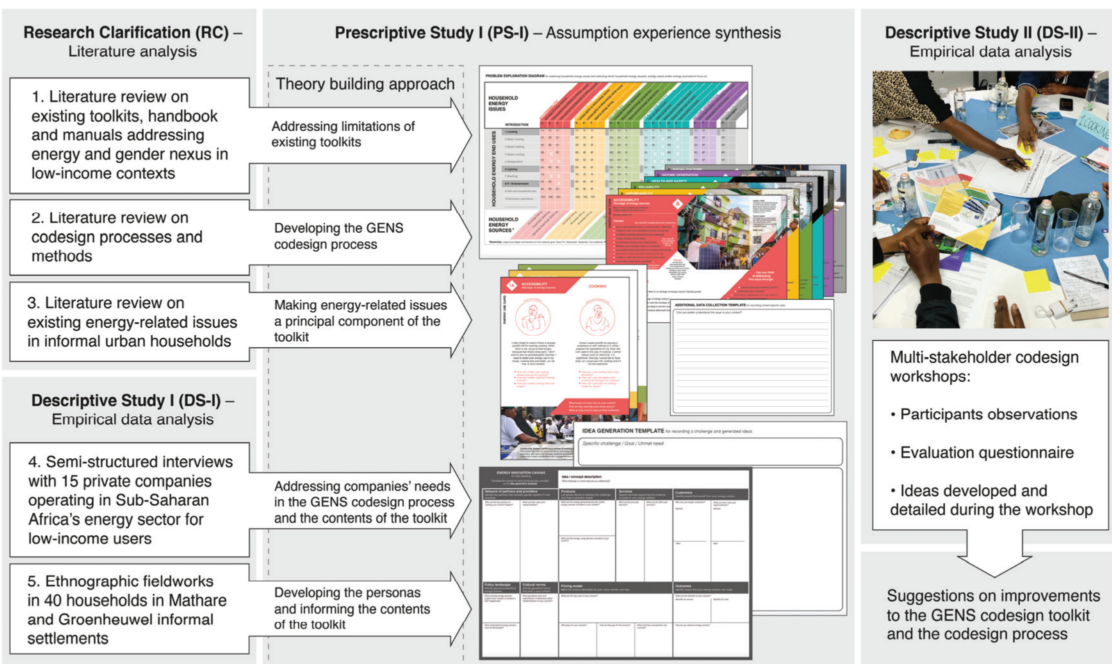


Figure 1. Design Research Methodology used to develop and evaluate the GENS codesign toolkit.

2.1. *Research Clarification (RC)—Literature Analysis*

Literature review on existing design supports (toolkits, handbooks and manuals) addressing the energy and gender nexus in low-income contexts. The aim was to understand what design supports are currently available for those wishing to design energy solutions with gender in mind and identify its limitations. The key search concepts were "energy", "gender mainstreaming" and "design support", and the specific Boolean phrase we used was as follows: (Energy) AND ((Gender) AND (Mainstream*) OR (Equality) OR (Equity) OR (Fairness) OR (Women)) AND ((Design) OR (Support) OR (Tool*) OR (Handbook) OR (Manual) OR (Method) OR (Guid*) OR (Project) OR (Training)). In simple terms, we searched for design supports that tackle the energy and gender nexus. The search was performed on the web and in Google Scholar since we knew that these kinds of supports are usually found in the grey literature. The search resulted in 20 design supports published between 2004 and 2019 (see Appendix A for the complete list). These supports included toolkits, handbooks and manuals published by international organisations, such as USAID [26], ADB [27,28], ENERGIA [29–31] and UNDP [32,33]. These supports were targeted towards a wide spectrum of stakeholders (policymakers, consultants, community groups, private sector companies, the academic community, etc.), and included a combination of strategies, methods, best practices and principles on how to consider and integrate gender into energy projects. The literature review on existing design supports showed that only 1 out of 20 existing supports we analysed focused specifically on urban environments [26]. While 5 of our analysed supports served the training purpose [30,31,33–35] and 10 facilitated qualitative data gathering (e.g., [27]), none of the supports were designated for idea generation or codesign. Furthermore, containing up to 176 pages of information [35], these toolkits require time-consuming preparations, and thus, their practical applicability is questionable. This review enabled us to identify the research gap: the lack of an applicable and effective toolkit that supports idea generation for gendered energy innovations in informal urban settlements.

Literature review on codesign processes and methods. The GENS codesign toolkit was developed to be used in codesign activities, where different stakeholders from different sectors engage in gendered energy innovation processes [24]. Therefore, the aim of this literature review was to identify what to consider when developing a toolkit that enables codesign processes characterised by complex multistakeholder collaboration. We analysed implemented codesign studies (e.g., [36]) and looked at the importance of facilitation [37] and dialogue between participants [38,39]. The literature review on the codesign process and methods was helpful for outlining the toolkit's elements and the codesign process to be adopted by the toolkit.

Literature review on existing energy-related issues in informal urban households. Design is often used as a problem-solving activity that results in creative solutions [40]. Therefore, understanding what problems currently exist in the energy scene of informal urban settlements was identified as a crucial step towards context-specific energy innovations. We collected the energy-related issues and clustered them into six main areas:

(1) Accessibility. This includes issues related to the shortage of energy sources (e.g., seasonal fuel availability [41]) and the time-consuming collection and preparation of energy sources (e.g., women spend four times longer than men collecting firewood [10]).

(2) Affordability. This considers problems connected with the limited ability to afford energy sources (e.g., the price of the fuels is a major factor in determining the household's fuel preference and energy consumption [42]), limited ability to afford energy-using devices (e.g., where there is an electrical connection, the use of electricity for cooking or heating may be difficult due to a high additional appliance cost [43]) and the need for energy saving (e.g., limiting the number of cooking times to reduce costs [12]).

(3) Reliability. This refers to aspects associated with unreliable electricity connections (e.g., [44]), poorly designed and serviced energy-using devices (e.g., poorly designed clean cooking appliances age and break easily, and this is combined with the lack of after-sale services, such as maintenance and repair [13]).

(4) Health and safety. This includes problems related to the lack of safety at home and on the streets (e.g., crime in the community because of the lack of street and public toilets lighting), indoor air pollution (e.g., due to lack of modern cooking systems [45]), energy sources effect on food taste (e.g., paraffin affects the taste of food when used for cooking [9]), and energy-related risks for health (e.g., accidental fires from the use of candles and kerosene stoves [42]).

(5) Income generation. This is about the lack of opportunities for women to be involved in the energy value chain (e.g., relevant roles within energy companies) and entrepreneurial activities [11].

(6) Social culture. This is related to the stigma associated with using or not using certain energy sources (e.g., in certain Kenyan communities, it is believed that charcoal is the best option for cooking certain traditional meals [42]).

The collected issues were included in the contents of the GENS codesign toolkit and informed the following data collection stages.

2.2. Descriptive Study I (DS-I)—Empirical Data Analysis

Semi-structured interviews with 15 private companies operating in sub-Saharan Africa's energy sector for low-income users. We believe that private energy companies that offer products and services to the residents in informal settlements are catalysts for change and primary users of the GENS codesign toolkit. We conducted one-hour semi-structured interviews that aimed to understand how companies design energy solutions and what (design) supports they use. The interviews were focused on discussing the following: (1) the gendered aspects that companies currently consider in the different stages of the design of energy solutions; (2) the methods and tools used and expertise involved in the design of energy solutions; and (3) the considerations they make when designing for informal urban areas, including energy-related issues addressed by the companies. We found out that the focus on gender is still limited among energy companies, and the application of readily available gender–energy nexus tools is non-existent [23]. However, companies are eager to learn about gender in energy and receive strategic design support to better mainstream gender in their energy projects. In-depth interview findings are presented and discussed in a working paper. The interview results were used to finalise the design process using the toolkit and contributed to the contents of the toolkit.

Ethnographic fieldwork in 40 households in Mathare (Kenya) and Groenheuwel (South Africa) informal settlements. The aim of the ethnographic data collection was to gain insight into how residents of the GENS case study locations manage energy-related issues identified from the literature review and semi-structured interviews. We applied remote rapid ethnographic data collection [46], which was conducted by the locally based community co-researchers from Mathare and Groenheuwel. Co-researchers worked in pairs and spent half a day in each household to (1) observe how women and men used energy devices, sources and services in their daily lives; (2) question the residents to reveal their unmet energy needs; and (3) collect ideas regarding energy solutions that were generated by people living in the settlements. The ethnographic data collection findings informed the development of personas—i.e., fictional characters representing different users—and were included in the contents of the codesign toolkit. Furthermore, the employment of community co-researchers strengthened the relationship between the GENS project and the communities, which is fundamental for the successful establishment of the GENS Living Labs and the organisation of multistakeholder activities.

2.3. Prescriptive Study I (PS-I)—Assumption Experience Synthesis

Data gathered during the RC and DS-I stages were used to develop the GENS codesign toolkit and its application process. We applied the theory-building approach [47] to synthesise the collected data into individual tools (combined to form a toolkit) and defined the toolkit's application codesign process. This process was inspired by the double diamond design approach (DDDA), which suggests exploring an issue "widely or deeply" and later, based on the exploration, taking a focused action [48].

2.4. Descriptive Study II (DS-II)—Empirical Data Analysis

The first version of the GENS codesign toolkit was tested during a full-day codesign workshop held in Nairobi, Kenya, in December 2021. The activity was facilitated physically by three GENS researchers from Brunel University London, the University of Nairobi and Stellenbosch University. The aim of the testing was to evaluate the toolkit's performance with its target users and observe the dynamics of the proposed codesign process. Three mixed data collection methods were applied to gather feedback about the toolkit's performance during the workshop: researchers' observations (qualitative data), participants' evaluation questionnaire (qualitative and quantitative data), and ideas developed and detailed during the workshop (qualitative and quantitative data). Qualitative data were analysed using thematic coding and classifying data into codes and themes to generalise gathered insights and ideas [49]. Quantitative data were analysed using a prescriptive statistics percentage tool [50] to define the proportion of people who gave a specific evaluation.

Based on the DRM, an evaluation questionnaire was made to evaluate the following of each element of the GENS codesign toolkit: (1) completeness: the extent to which the toolkit contains logical and detailed content about gender, energy and informal urban settlements; (2) usability: the extent to which the toolkit is easy to understand and apply; and (3) effectiveness: the extent to which the toolkit enables users to understand current energy-related issues and generate gendered energy ideas for informal urban settlements.

3. GENS Design Toolkit

This section outlines the elements of the GENS codesign toolkit and describes the proposed codesign process.

3.1. Elements of the Toolkit

The first version of the GENS codesign toolkit consists of six tools: a problem exploration diagram, a set of 17 energy issue cards, a set of 45 energy end-use cards, an additional data collection template, an idea generation template and an energy innovation canvas. All tools were made to be printed out to be easily shared among users, studied and evaluated during the toolkit's testing activities. The relations between these six tools and how they support the proposed codesign process are described in Section 3.2.

3.1.1. Problem Exploration Diagram

The purpose of the problem exploration diagram is to help users to explore existing energy-related issues in informal urban households and their linkages with different energy sources. It is the introductory tool of the toolkit, and thus, it was made to provide an overview of a wide variety of issues that can be tackled by the toolkit. Furthermore, it helps to navigate the toolkit by referring to those cards to be used for further problem exploration and idea generation. The list of 17 issues included in the diagram was informed by the findings from the literature review, interviews with energy companies and ethnographic data collected in Mathare and Groenheuwel informal settlements. The layout of the diagram was designed to highlight the household energy issues; thus, six different block colours were used to represent the six identified categories of the issues. Figure 2 shows the problem exploration diagram and its key components.

3.1.2. Energy Issue Cards

The aim of the energy issue cards is to provide in-depth information about each of the household energy issues listed on the problem exploration diagram introduced above. In addition, it was made to support idea generation. There is a total of 17 energy issue cards, one for each issue named from A to R. The information listed on the cards was informed by the literature review findings, ethnographic data collection and insights gained from the interviews with energy companies. Each colour used on the card refers to a category of household energy issues addressed on the card. Figure 3 illustrates one of the energy issue cards and summarises its key features.

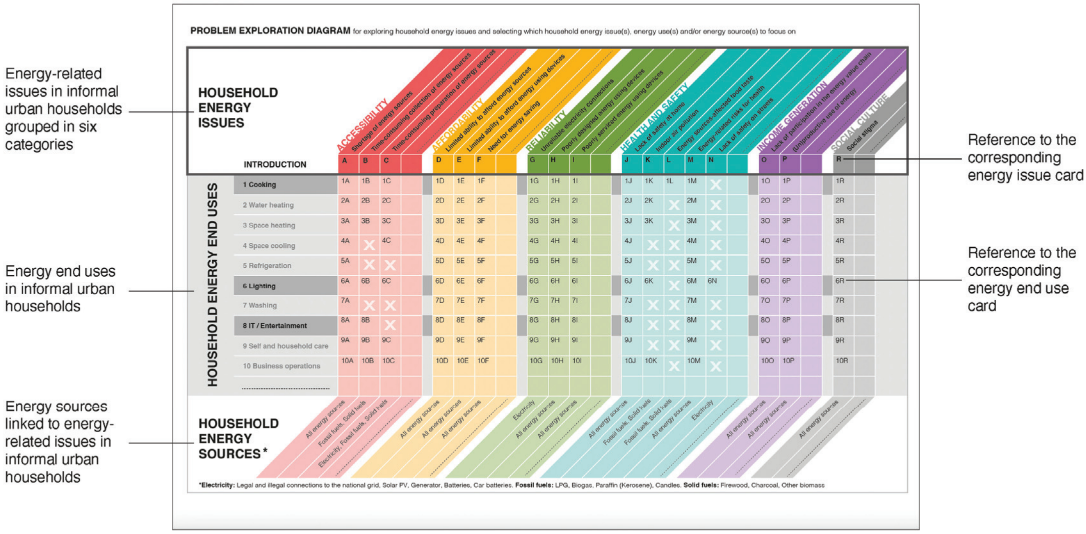


Figure 2. Problem exploration diagram printed on an A3-sized piece of paper.

Figure 3. One of the seventeen energy issue cards printed on an A5-sized piece of paper.

3.1.3. Energy End-Use Cards

The goal of the energy end-use cards is to provide a first-hand user experience about household energy issues for different energy end uses. The cards includes persona stories that were collected during the ethnographic research in Mathare and Groenheuwel informal settlements: each card contains one persona from each settlement, either a woman or a man. The energy and use cards were also made to support idea generation. The vertical layout of the cards was chosen to differentiate the cards from the energy issue cards. In order to maintain consistency, the single colour used on the card refesr to the category of the household energy issue. The first version of the toolkit includes the cards addressing cooking, lighting and IT/entertainment energy end uses. Figure 4 pictures one of the energy end-use cards with its key components.

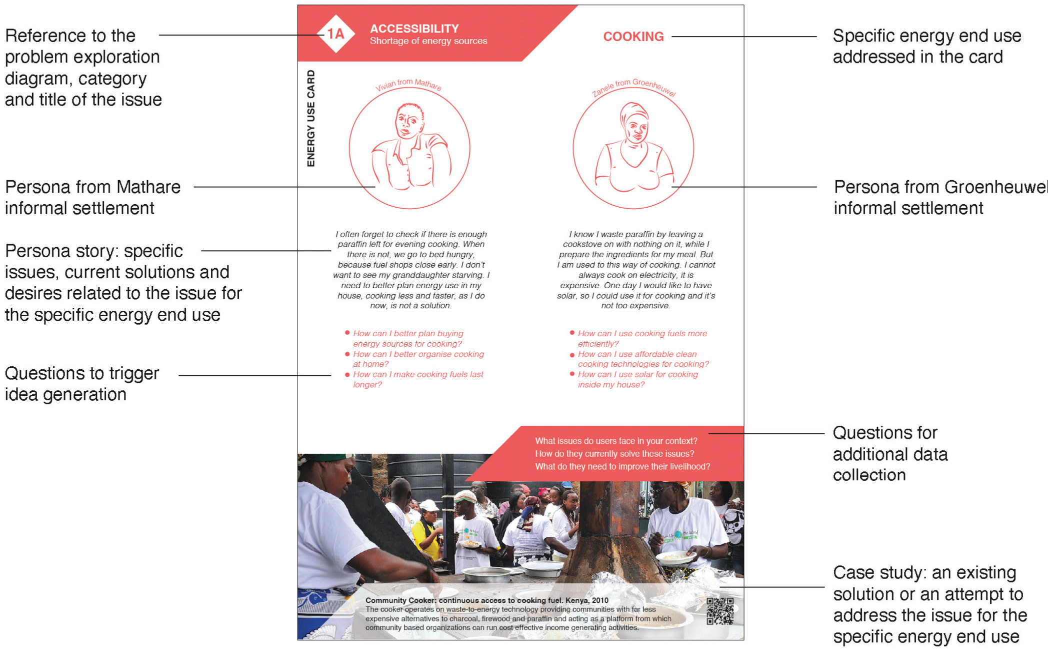


Figure 4. One of the forty-five energy end-use cards printed on an A5-sized piece of paper.

3.1.4. Additional Data Collection Template

The purpose of the additional data collection template (Figure 5) is to provide space for the users to collect context-specific data about household energy issues. This template was made to record answers to data collection questions listed on the energy issue cards and energy end-use cards.

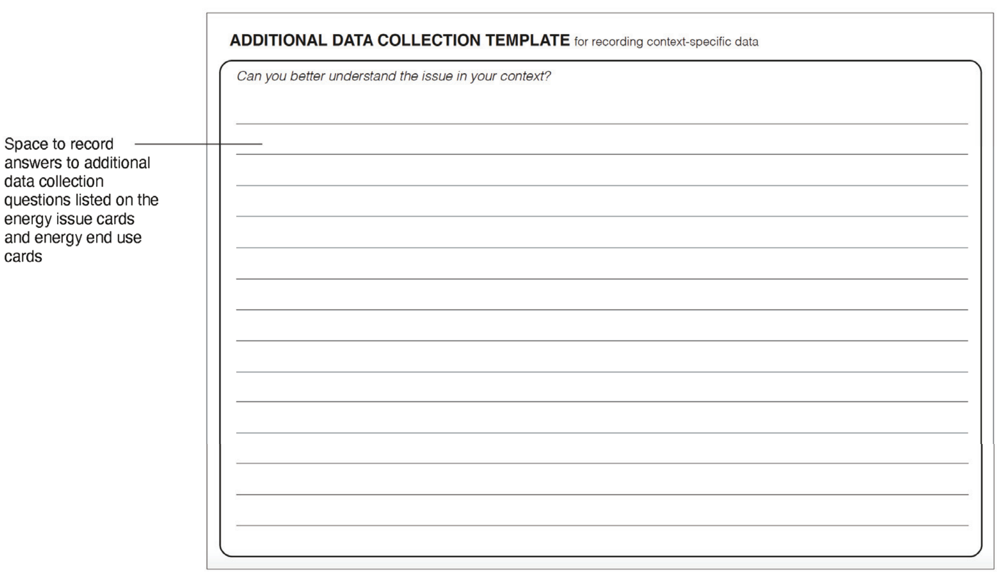


Figure 5. Additional data collection template printed on an A5-sized piece of paper.

3.1.5. Idea Generation Template

The idea generation template (Figure 6) is a space for describing a specific design challenge and recording ideas addressing the challenge.

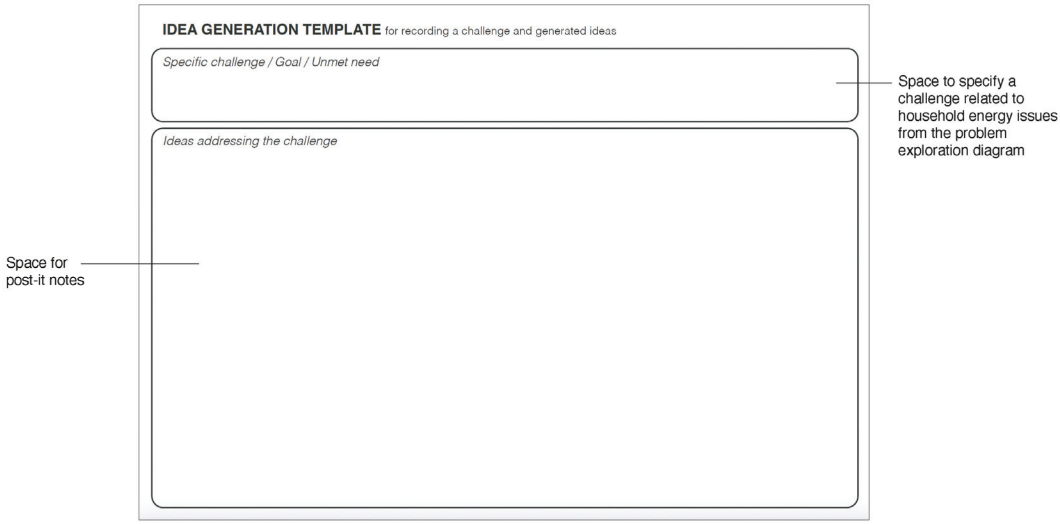


Figure 6. Idea generation template printed on an A3-sized piece of paper.

3.1.6. Energy Innovation Canvas

The purpose of the energy innovation canvas (Figure 7) is to describe the essential elements of the most promising idea(s) listed on the idea generation template and to understand their viability for further development and implementation. The canvas was adapted from the famous Business Model Canvas [51] and supplemented with the GENS research project-specific sections, including the energy policy landscape, cultural norms, and social and environmental outcomes.

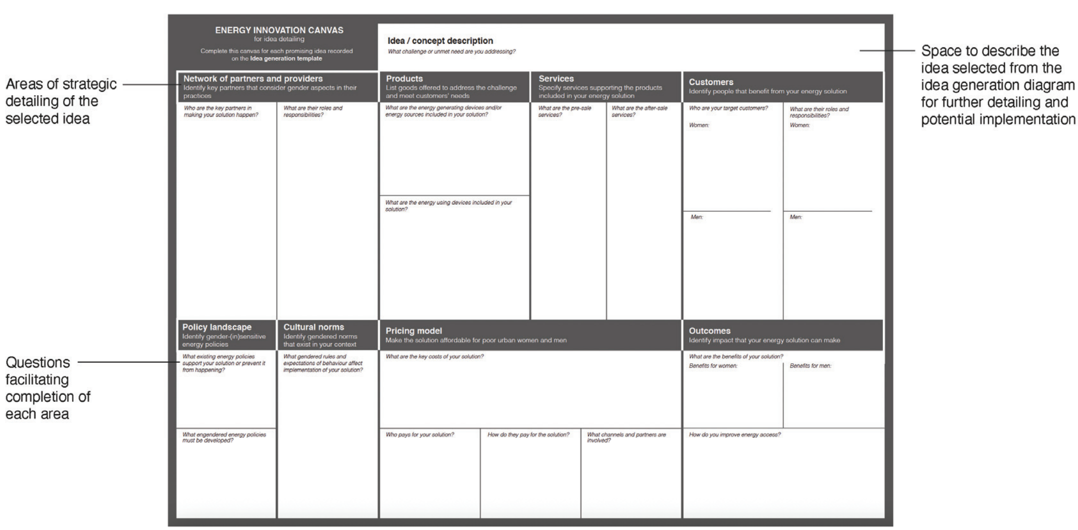


Figure 7. Energy innovation canvas printed on an A2-sized piece of paper.

3.2. The GENS Codesign Process Using the Toolkit

Based on the double diamond design approach (DDDA) [48] and addressing the purpose of the GENS Living Labs, we defined the GENS codesign process as comprising three main stages (Figure 8):

1. **Problem exploration stage (equivalent to the "discover" and "define" stages of the DDDA).** Tools: problem exploration diagram, energy issue cards, energy end-use cards and additional data collection template.

During this stage, the toolkit's users learn about existing energy-related issues in informal urban households, the causes of these issues, and the effects on both genders and current solutions implemented to address these issues. During this stage, users are also encouraged to collect additional context-specific data to better understand how the issues listed in the toolkit affect users from the targeted informal settlement. At the end of this stage, users define a specific problem to focus on in the next stages.

2. **Idea generation stage (equivalent to the "develop" stage of the DDDA).** Tools: *energy issue cards*, *energy end-use cards* and *idea generation template*.

The second stage is dedicated to generating ideas that address the specific problem defined in the previous problem exploration stage. During this stage, the toolkit's users brainstorm a wide range of ideas and, if needed, go back to the problem exploration stage to gain additional information and inspiration.

3. **Idea detailing stage (equivalent to the "deliver" stage of the DDDA).** Tools: *idea generation template* and *energy innovation canvas*.

During the final stage, the toolkit's users select one idea or a set of ideas developed in the previous stage that they see the most potential in implementing. They think about the enabling environment needed to make their selected idea a reality and its effects on society and the environment. At the end of this stage, the toolkit's users have an overview of the range of aspects of their final ideal, including products, services and the supporting infrastructure.

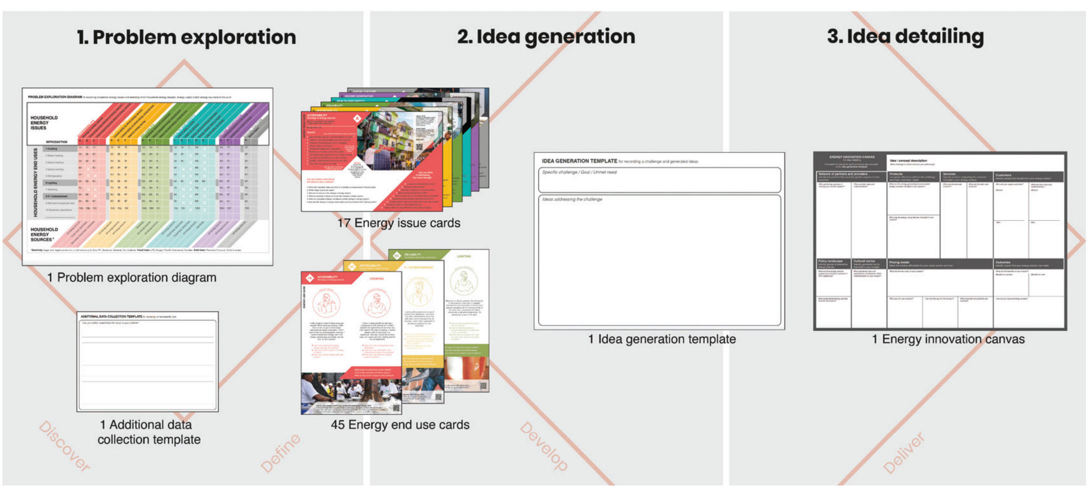


Figure 8. The elements of the GENS codesign toolkit in relation to the corresponding stages of the GENS codesign process and the double diamond design approach.

4. Case Study: The GENS Codesign Workshop

The GENS codesign workshop invited community members from Mathare informal settlement, as well as private and public stakeholders, to codesign gendered energy solutions for Mathare residents. The participants were representative of the toolkit's intended audience: multiple stakeholders interested in solutions to sufficiently meet the energy needs in informal settlements. In total, 25 participants—15 women and 10 men—took part in the workshop. The participants were recruited via email. More than half of the participants attended previous stakeholder engagement activities organised by the GENS researchers, and thus, they already knew each other and the GENS team. All participants were able to speak English and Swahili.

At the beginning of the workshop, the participants were split into five multistakeholder groups of between four and six members. Each group included representatives from one of the five private companies and Mathare community and either a researcher or a policymaker (Table 1).

Table 1. Stakeholders who attended the codesign workshop.

Stakeholder's Code and Group Allocation		Sector	Role	Gender
PC1	Group 1	Private company (a)	Solar technician	Female
PC2	Group 1	Private company (a)	Solar technician	Male
PC3	Group 1	Private company (a)	Operations officer	Female
PC4	Group 2	Private company (b)	Sales and experiential manager	Female
PC5	Group 2	Private company (b)	Customer care	Female
PC6	Group 3	Private company (c)	Strategy coordinator	Female
PC7	Group 3	Private company (c)	Business development	Female
PC8	Group 3	Private company (c)	Head of legal compliance	Female
PC9	Group 4	Private company (d)	Product manager	Female
PC10	Group 4	Private company (d)	Product manager	Female
PC11	Group 5	Private company (e)	Grants and impact manager	Female
MC1	Group 1	Mathare community	Community leader	Male
MC2	Group 1	Mathare community	Energy user	Female
MC3	Group 2	Mathare community	Energy retailer	Male
MC4	Group 2	Mathare community	Community leader	Male
MC5	Group 3	Mathare community	Energy retailer	Male
MC6	Group 3	Mathare community	Community leader	Female
MC7	Group 4	Mathare community	Community leader	Male
MC8	Group 5	Mathare community	Energy retailer	Female
MC9	Group 5	Mathare community	Energy user	Male
RS1	Group 2	Research institute (a)	Researcher	Male
RS2	Group 3	Academia (a)	Lecturer and researcher	Male
RS3	Group 4	Research institute (b)	Executive director	Female
RS4	Group 5	Academia (b)	Researcher	Female
GV1	Group 5	Government	Policymaker	Male

The workshop lasted 5 h 30 min excluding breaks. The structure of the workshop (Table 2) was organised to follow the GENS codesign process introduced in the section above. At the beginning of the workshop, the facilitator from Brunel University London presented the background information about energy (existing household energy issues), gender (best practices and principles for gender mainstreaming in the energy sector) and informal urban settlements (overview of Mathare and Groenheuwel). Finally, the GENS codesign toolkit was introduced and circulated to the participants. Later, each participating group was asked to select one design brief to focus on for the duration of the workshop.

Three design briefs, addressing focus areas of participating companies and energy end uses included in the toolkit—cooking, lighting and IT/entertainment—were suggested by the facilitator:

(1) Design a clean cooking solution for indoor cooking using waste as a resource (selected by two groups);
(2) Design an outdoor lighting system for improved safety in the settlement (selected by one group);
(3) Design a communal entertainment system for the whole family (selected by two groups).

Table 2. The agenda of the GENS codesign workshop.

Stage	Activity	Duration
Introductions by the facilitator	Presentation on the household energy issues in informal settlements	60 min
	Presentation on the best practice principle for gender mainstreaming in the energy sector	
	Presentation on comparison between Mathare and Groenheuwel informal settlements	
	Introduction to the GENS codesign toolkit	
Problem exploration in groups	Selection of design briefs by the participants	60 min
	Selection of three household energy issues to address from the problem exploration diagram and analysis of the energy issue cards	
	Additional data collection (by answering questions on the energy issue cards)	
	Analysis of energy end-use cards	40 min
	Additional data collection (by answering questions on the energy end-use cards)	
Idea generation in groups	Idea generation	60 min
	Presentations of populated idea generation diagrams	25 min
Idea detailing in groups	Idea selection for detailing	40 min
	Idea detailing using the energy innovation canvas	
	Presentations of the populated energy innovation canvas	25 min
Feedback	Discussion and feedback using evaluation questionnaires	20 min

After selecting the design briefs, the participants were ready to follow the step-by-step codesign process guided by the facilitators (Figure 9). Each group had to identify which of the three household energy issues listed on the problem exploration diagram they wanted to address (1). Participants discussed the information provided on the diagram and energy issue cards. After deciding the three issues to focus on, they were asked to better understand these issues in relation to the Mathare context by questioning group members and recording answers on the additional data collection templates (2). The same process was repeated with the energy end-use cards (3). After the problem exploration was finalised, the groups started generating ideas addressing the three selected issues. The groups populated three idea generation diagrams each (4) and presented them during group presentations. The final stage was idea selection and detailing. Participants had to select the most promising of their generated ideas and combine them in one energy innovation canvas per group (5). The workshop was concluded with group presentations on final detailed ideas. This was followed by a collective discussion on the toolkit and the collection of the evaluation questionnaire (6).

Figure 9. The toolkit's application during the codesign workshop. (**1**) Identification of energy issues to address; (**2**) Discussing the information provided on the diagram and energy issue cards; (**3**) Discussing the information provided on energy end-use cards; (**4**) Generating ideas and writing them down on the idea generation diagrams; (**5**) Selecting and detailing ideas and combining them in one energy innovation canvas; (**6**) Presenting results.

4.1. Findings from the GENS Codesign Workshop

This section presents findings from three data collection methods: researchers' observations, participants' evaluation questionnaire, and ideas developed and detailed during the workshop.

4.1.1. Observations of the Workshop Participants

Participant observations were carried out by the facilitators throughout the problem exploration, idea generation and idea detailing stages of the codesign process. The aim was to collect qualitative insights on participants' behaviour during the use of the toolkit to assess the design of the codesign workshop. The facilitators moved between the tables listening to group conversations and noting down all noticeable insights. Insights from the facilitators' personal observations were linked to the workshop design and facilitation itself, group work dynamics and participant engagement, and the process of using the GENS codesign toolkit.

Workshop design and facilitation. First, it was observed that during the workshop, the participants kept on referring to the contents of the presentations given by the facilitators. Second, even though the facilitators guided the participants through the different elements of the toolkit throughout the workshop, the participants required extra clarification on how to select household energy issues and adapt the idea generation questions listed on the cards to a specific design brief they chose to address. Third, it was observed that two participating groups used some elements of the toolkit slightly differently from how it was explained by the facilitators: one group started by reading all energy issue cards instead of first selecting the issues from the problem exploration diagram to focus on, while the other group generated ideas for all three selected issues simultaneously rather than one at a time. However, both groups achieved the required results by the end of the workshop.

Groupwork and participant engagement. Energetic discussions between the group members were easy to notice, as the whole venue became noisy once the first group task—the selection of a design brief—was introduced. It was observed that the toolkit helped participants from different backgrounds to communicate: the contents of both types of cards worked as a conversation starter and helped participants to open up and share ideas. Even though the contents of the toolkit were written in English, the participants discussed them in both English and Swahili. It was observed that the involvement of Mathare community members made the group work particularly lively because other stakeholders were interested in better understanding the context by questioning the community members. The community representatives also informed the choice of household energy issues. However, not all the participants were fully engaged in the group work. RS1 was more interested in reading through the toolkit's materials on his own rather than engaging in the group discussions. Later, he shared that the toolkit was very relevant to his personal work, and thus, he was fascinated by the amount of information it provided. In another group, the participation of the energy provider was vague, which was most likely caused by the very talkative researcher who took the lead. The lack of participant engagement could be addressed by supportive and sensible facilitation.

The use of the GENS codesign toolkit. The researcher who praised the contents of the toolkit was not the only participant who found the data of the toolkit interesting. It was observed that the case studies included in the cards helped the participants to understand the rest of the contents of the cards without having sufficient English language skills. PC9 had previous experience using various design tools and complimented the case studies as a particularly informative element of the GENS toolkit. In addition, group conversations and presentations considered gendered aspects, showing that the toolkit encouraged gender-focused thinking. During informal conversations after the workshop, energy providers from two companies expressed their interest in applying the toolkit in their companies' work.

Despite the positive comments and enthusiasm from the participants, observations also revealed a few limitations of the toolkit. Some participants struggled to understand the data collection and idea generation questions written on the cards; they had to read the same question more than once. Some participants had questions on how to complete the energy innovation canvas and suggested that the canvas could include possible options to choose from: e.g., PC10 was not sure what to include in the "Service" section. Finally, it was observed that the problem exploration diagram and the idea generation template printed on the A3-sized paper were too small, as participants found them difficult to share and read.

4.1.2. Toolkit's Evaluation Questionnaire

The evaluation questionnaire was designed to assess the completeness, usability and effectiveness of the GENS codesign toolkit and its individual elements. The questionnaire consisted of quantitative closed-ended scale questions and qualitative open-ended questions. Each participant was handed a printed copy of the questionnaire to be completed at the end of the workshop. Qualitative feedback was divided into positive comments praising the toolkit and its individual elements, suggestions for improvements and negative comments criticising the toolkit without suggesting improvements.

(1) All Elements of the GENS Codesign Toolkit

Gendered perspective included in the toolkit. All aspects of the whole toolkit received very high evaluation scores (Table 3). The toolkit's ability to provide a gendered perspective was praised by the participants: "*So far this is the most integrated gender toolkit for product design I'm so excited to keep using it*" (PC9). The feature of how the toolkit incorporated gendered perspectives was evaluated 4.56 out of 5, meaning there was still room for improvement. The participants noticed the absence of considerations regarding how energy affects different age categories of both genders. In terms of the contents, the participants found the case study descriptions too generic: "*Some innovations, concepts are a little generalised. I think we can only be intentional by intentionally involving both genders*" (PC2). The community members suggested focusing more on gender involvement in the energy value chain, particularly in the installation and maintenance stages. In terms of the workshop design, the participants suggested that both genders should have equal rights to speak about their issues and express their views on design.

Table 3. Quantitative evaluation of the features of the GENS codesign toolkit.

	Features Evaluated	Question	Score (out of 5)
	Completeness, usability and effectiveness	To what extent is the gender perspective included in the toolkit (i.e., issues, needs, solution etc. of women and men energy actors?)	4.56
		To what extent is the toolkit helpful to understand the energy context of informal urban areas?	4.72
		To what extent was the toolkit helpful to facilitate discussion in your group?	4.75

Energy context of informal urban settlements presented in the toolkit. The toolkit was found to be a useful source for helping understand the energy context of the informal settlement: "*I think I got to understand the energy situation in poor urban areas in a way that has not been explored before. Having actors from those regions was a huge bonus*" (PC7). The participants requested more context-specific information to be included in the toolkit, such as images from the settlement and descriptions of current "*initiatives in place to address energy issues or any upcoming initiatives*" (PC8). The participants were also interested in seeing the context-specific statistics. In terms of the workshop design, the participants would like to see more actors from each role in the energy sector and a stronger representation of the community members.

Facilitation of group discussion. The toolkit's ability to facilitate group discussion received the highest evaluation score (4.75/5): "*Very useful for getting diverse perspectives to collaborate*" (RS3). Discussions were so engaging that the participants found the workshop too short for the number of activities and discussion points they had to complete: "*Having enough time for discussion in order to allow everybody to give his/her opinions*" (MC5). In addition, the participants suggested having a skilled facilitator in every group to guide the discussion and ensure the inclusivity of ideas.

(2) Problem Exploration Diagram

Completeness. Some participants found the problem exploration diagram complete: "*The diagram was very comprehensive in content*" (MC9), while others suggested adding more details, such as real-world examples and images: "*it could be more specific and detailed*" (MC8). However, the participants agreed that "*with proper guidance received from the facilitator it was easier to comprehend and use [it]*" (PC11). Finally, the issue of sustainability, which was perceived as critical by the participants, was not directly considered in the diagram.

Usability. The colours and overall layout of the diagram were complimented by the participants: "*The diagram was very easy to use by an ordinary person in the urban poor areas*" (MC1). The usability feature of the problem exploration diagram received the lowest evaluation point of all elements of the toolkit, yet still high (4.24/5) (Table 4). The participants expressed their dissatisfaction regarding the small text size that made the legibility of the diagram difficult and requested more than one copy per group. The participants also suggested testing the diagram with colour blind and short-sighted people.

Effectiveness. Despite the contents and usability limitations, the diagram was effective in helping to explore and select energy issues (4.6/5): "*I think the diagram covers a large scope and it's been compressed to cover everything nicely and still be understood*" (PC1). The participants emphasised the importance of having sufficient use guidelines and facilitation since the diagram "*might seem overwhelming at first*" (PC3).

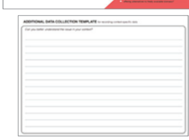
Table 4. Quantitative evaluation of the features of the problem exploration diagram.

	Feature Evaluated	Question	Score (out of 5)
	Completeness	To what extent are the contents of the diagram complete (i.e., included household energy issues, energy end uses and energy sources)?	4.29
	Usability	To what extent is the diagram easy to read and use (in terms of layout/colours/shapes etc.)?	4.24
	Effectiveness	To what extent is the diagram helpful to explore existing household energy issues?	4.6
		To what extent is the diagram helpful to select household energy issues, energy end uses and energy sources for further exploration and idea generation?	4.58

(3) Energy Issue Cards and Additional Data Collection Template

The energy issue cards were the most successful part of the toolkit according to the quantitative evaluation score given by the workshop participants (Table 5).

Table 5. Quantitative evaluation of the features of the energy issue cards and the additional data collection template.

	Feature Evaluated	Question	Score (out of 5)
 	Completeness	To what extent are the contents of the cards complete (i.e., causes of the issue, gender insights, idea generation and data collection questions, case study example)?	4.68
	Usability	To what extent are the cards easy to read and use (in terms of layout/colours/shapes etc.)?	4.68
	Effectiveness	To what extent are the cards helpful to learn about household energy issues?	4.76
		To what extent are the cards helpful to generate ideas?	4.84

Completeness. The participants' opinions differed on the contents of the energy issue cards. Some of them found that the cards contained too much information and too many questions: "*Look at reducing the areas, especially questions to answer given the limited time*" (PC10). The other participants requested additional information, such as more roles of each gender, the aspects of government involvement in the energy sector and more context-specific case studies.

Usability. The community members found the cards easy to understand because of the simple English language used to explain their contents. However, similarly to the problem exploration diagram, the participants requested larger text sizes and more copies of the cards to be provided to each group to facilitate legibility and sharing. Additionally, the usability could be improved by including use guidelines: "*My eyes weren't quite sure where to start so perhaps there could be an arrow just for easier/quicker comprehension*" (PC9). One community member suggested combining the cards with the additional data collection template by adding a context-specific comment section to the cards.

Effectiveness. The cards' ability to help generate ideas received the highest evaluation score (4.84/5) out of all the elements in the toolkit. The participants found the case studies particularly insightful and helped to trigger ideas: "*The global examples on the cards were excellent in helping teams think out of the box*" (PC7); in terms of discussing the idea generation questions: "*The specific questions really focused the conversation*" (PC4).

(4) Energy End-Use Cards and the Additional Data Collection Template

It was observed during the workshop that the persona stories made the energy end-use cards educational and engaging: "*Best part of the toolkit!*" (RS1). "*I think I had a better experience with these cards than the previous*" (MC5).

Completeness. Several participants agreed that the energy end-use cards were complete: "*They should remain just like as they are*" (MC7), "*No additions are needed*" (PC4). The contents of the cards received an evaluation score of 4.6 out of 5 (Table 6), and thus, could be improved. The participants highlighted the lack of gender considerations in the cards: "*Let the questions have a gender component. Ask the question for a woman and the same question as it applies to men*" (PC2); they also demanded more context-specific case studies.

Table 6. Quantitative evaluation of the features of the energy end-use cards and the additional data collection template.

	Feature Evaluated	Question	Score (out of 5)
	Completeness	To what extent are the contents of the cards complete (i.e., persona stories, idea generation and data collection questions, case study example)?	4.6
	Usability	To what extend are the cards easy to read and use (in terms of layout/colours/shapes etc.)?	4.68
	Effectiveness	To what extent are the persona stories helpful to learn about household energy issues for specific household energy end use?	4.8
		To what extent are the cards helpful to generate ideas?	4.68

Usability. The overall layout and the colours used in the cards were complimented by the workshop participants: "*The colours are bright enough for one to read*" (MC2). However, the small text size and the lack of copies provided to each participating group were criticized by the participants. The additional data collection template could include more instructions on how to use it.

Effectiveness. The educational aspect of the persona stories included in the cards received the highest quantitative evaluation (4.8/5). The participants requested more stories from other African countries: "*The stories help us understand the energy situation in different countries and so we are able to develop innovations that cut across*" (PC8). However, the participants pointed out the lack of linkage between the specific challenge they chose to address and the questions listed on the cards: "*It was a little confusing when we had to address the challenge and didn't really quite figure out the questions in relation to persona and the challenge being addressed*" (RS4).

(5) Idea Generation Template

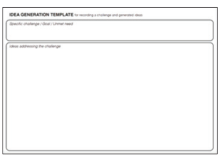
All features of the idea generation template received relatively high evaluation scores (Table 7), making it the third most successful tool across both types of cards.

Completeness. The participant feedback regarding the contents of the template was very positive, with most of the comments expressing satisfaction about its completeness: "*Nothing can be improved*" (MC4), "*It is good and organised no need to change anything*" (MC8). One researcher suggested including the identification of the actor network as the next step after idea generation.

Usability. In terms of usability, the workshop participants requested that the template be larger, followed by increased text size, so that more ideas can be recorded. The participants, used to colourful tools they used previously, suggested including colours in the template: "*Stop making it look like an exam paper*" (MC2).

Effectiveness. In addition to idea generation, the template was also made to describe a challenge and help to select a promising idea(s) for further development. RS2 highlighted that it is a "*good way to group ideas by solution. Sticky notes really helped*". However, the template's ability to support idea selection could be improved: "*Use stage wise selection of ideas-start with a bigger number and applying a set criterion reduce them until you have the most critical ones.*" (GV1). The participants suggested that the workshop design could ensure that everybody explains their opinions alone, while the presentations are recorded for future use.

Table 7. Quantitative evaluation of the features of the idea generation diagram.

	Feature Evaluated	Question	Score (out of 5)
	Completeness	To what extent are the contents of the template complete?	4.76
	Usability	To what extent is the template easy to read and use (in terms of layout/colours/shapes etc.)?	4.6
	Effectiveness	To what extent is the template helpful to record a challenge?	4.71
		To what extent is the template helpful to record ideas?	4.79
		To what extent is the template helpful to select promising ideas for further detailing?	4.75

(6) Energy Innovation Canvas

Completeness. The workshop participants complimented the comprehensiveness of the canvas and compared it to the Business Model Canvas, with which most of them were familiar: "*The content is elaborated, nothing to be improved*" (MC2), "*I like this better than the business model canvas*" (RS3). However, several participants found the contents of the canvas repetitive. The customers' section was named as ambiguous for some ideas, and the participants suggested that the canvas could be customised depending on the ideas. Furthermore, the participants highlighted the absence of the aspect of sustainability and social issues.

Usability. The participants found the canvas "*great and easy to use. It has a natural flow*" (PC10). The comments regarding the usability of the canvas were similar to the ones directed to the idea generation template: the participants requested more colours "*to make it exciting*" (PC3) and more space in each section. PC10 suggested that the usability could be facilitated by numbering a suggested route for completing the diagram.

Effectiveness. The canvas feature to help detail the selected idea received the highest evaluation score (4.68/5) (Table 8) compared to other features: "*The canvas adequately captured value proposition for the innovation and a benefit matrix*" (PC4). However, some sections included in the canvas could not be completed during the allocated time: "*We were unable to exhaust our discussions for each section*" (PC5). Furthermore, an additional template for the problem statement could be introduced to support concept descriptions.

Table 8. Quantitative evaluation of the features of the energy innovation canvas.

	Feature Evaluated	Question	Score (out of 5)
	Completeness	To what extent are the contents of the canvas complete (i.e., sections and corresponding questions)?	4.67
	Usability	To what extent is the canvas easy to read and use (in terms of layout/colours/shapes etc.)?	4.56
	Effectiveness	To what extent is the canvas helpful to describe the selected idea?	4.64
		To what extent is the canvas helpful to detail the selected idea describing each section?	4.68

4.1.3. Ideas Developed and Detailed during the Workshop

To triangulate with the findings from the observations of participants and the evaluation questionnaire, we also analysed the ideas recorded by each group on the idea generation diagrams. This enabled us to evaluate the outcomes that the toolkit helped to produce. We aimed at understanding which household energy issues were selected by the participants and the amount, relevance and originality of the developed and detailed ideas.

Each of the participating groups recorded between 18 and 45 ideas in one hour. Each group consisted of between four and six participants, meaning that each participant developed between 3 and 11 ideas. Prior to the idea generation session, the facilitators introduced the most common brainstorming principles and reminded the participants to record all ideas on Post-It notes. However, the participants often forgot to write down the ideas they shared verbally within the group, especially if they engaged in energetic discussion.

The participants developed ideas addressing three household energy issues they selected at the beginning of the workshop. Eleven different issues were selected by the participants out of the seventeen included in the toolkit, while four of them were selected twice. The participants selected issues from all six categories: accessibility (one issue); affordability (two issues); reliability (two issues); health and safety (three issues); income generation (two issues); social culture (one issue). Therefore, the ideas developed by the participants suggested energy solutions addressing a great range of energy-related issues in informal urban settlements.

The GENS codesign toolkit was developed to combine gender, energy and informal urban settlements. Therefore, we looked at whether and how the recorded ideas included all three elements. Most of the recorded ideas included the energy aspect and focused on low-income urban areas, e.g., "*Community kitty to maintain and service the street lighting, facilitated by community leader living in the area*" (group 3) and "*Smart systems to track illegal connections*" (group 5). In terms of gender inclusion, there were some ideas recorded that included the terms "women", "men", and "gender", e.g., "*Role reversals. Fun ways to feel what it is like to be the opposite gender*" (group 4) and "*Awareness on how to create innovations using waste collected from the community. Involve youth and women*" (group 3). Several ideas included youth and communities, which referred to both genders: "*Training/sensitisation/awareness on how to create innovations using waste collected from the community. Involve youth and women*" (group 3). Even though gender was not specified in most of the ideas recorded on Post-It notes, group discussions and presentations included gender considerations. During the idea detailing stage, the energy innovation canvas encouraged participants to consider both genders, energy and informal urban settlements, and thus, the final detailed ideas sufficiently combined all three elements.

In terms of creativity and originality, the ideas ranged from generic: "*Energy efficient appliances*" (group 2), to elaborated and context-specific: "*Feasibility study for wind power to generate electricity to power outdoor lighting (Kosovo is located on a hill with potential for wind power generation)*" (group 3). Group 4, which addressed a communal entertainment facility challenge and included a design expert, developed particularly original ideas that did not repeat any information included in the toolkit: "*Self-defence classes for women-Kenya Karate Grannies*", "*Mural/artwork for education on the electrical safety*" and "*Recruitment events/contests for sharing skills*" to name a few. In fact, the expertise of group members was reflected in the recorded ideas. Group 5, which also focused on a communal entertainment facility and included a policymaker, developed technical, cost and regulations-oriented ideas: "*Different billing schemes based on income level*", "*Set standards for imports manufacturing of energy devices*" and "*Government to: formulate policy to provide incentives to enterprises to lower cost of energy devices*".

5. Discussion

The first empirical application of the GENS codesign toolkit helped to identify its strengths, weaknesses, opportunities and threats. In this section, we reflect on the outcomes of the workshop and discuss future work.

5.1. Strengths of the GENS Codesign Toolkit and the Codesign Process

The high scores given in the toolkit's evaluation questionnaire (no less than 4.24/5 for a single feature) showed that the workshop participants enjoyed using the toolkit and considered it a successful instrument. The amount of data collected by the GENS researchers (through literature reviews, interviews with companies and ethnographic fieldwork) and included in the toolkit was found to be useful and appreciated by the users. Persona stories were found to be particularly engaging and educational. Those stakeholders who are responsible for energy provision constantly seek for better understanding of low-income users, who are often difficult to access and get to know. Therefore, they demanded more persona stories that illustrate different contexts. In addition, case studies helped to stimulate creative idea generation. In terms of the layout, the toolkit's visual design was complimented by the participants.

Active participant engagement, which is critical for the success of codesign, was observed during the workshop. The toolkit, and especially both types of cards, stimulated lively discussions and successfully supported idea generation. Context-specific data collection during the workshop encouraged conversations between different stakeholders and involved Mathare community members who helped others understand the Mathare energy scene. As a result, the majority of generated ideas was context-specific and targeted low-income urban communities. The variety of household energy issues selected by the participants to address showed that the selection of issues provided in the toolkit was sufficient and useful. Each group, which comprised between four and six members, generated between 18 and 45 ideas in one hour, demonstrating the toolkit's ability to support idea-brainstorming sessions. Some of the developed ideas were either gender-focused or indirectly considered both genders. The final idea-detailing activity ensured that gender considerations were incorporated into the final solution.

5.2. Weaknesses of the GENS Codesign Toolkit and the Codesign Process

The testing showed that the toolkit, and especially the introductory problem exploration diagram, could be more "gendered", i.e., include more roles of both genders and specify issues, needs and capabilities for different age groups of women and men. Furthermore, the sustainability potential of using the toolkit was not clear. The workshop participants highlighted the absence of Kenyan context-specific information, such as statistical analysis of energy use and preferences, local initiatives and images of real community members. Our aim was to create a toolkit applicable in different contexts. However, this requirement could be addressed by providing context-specific information prior to the workshop and including links to online databases and local case studies in the toolkit. It was observed that the information provided in the toolkit could be difficult to understand because of the amount of text and the English language, which was not native to most of the participants. The toolkit could potentially be less textual, more visual and even translated to local languages. In terms of the layout, the text size of all the toolkit's elements was too small, even for the A3-sized paper, making comprehension of the information challenging.

In terms of the codesign process, some participants experienced a lack of linkage between different stages, as the questions listed on the cards cannot be always directly applied to the variety of challenges selected by the users. In addition, each element of the toolkit was also lacking use guidelines written on them: it was not always clear where to start reading the provided information and how to use the templates and the energy innovation canvas. Moreover, there was a lack of support for "the most promising" ideas selection before the idea detailing exercise. These issues can be addressed by updating the contents of the toolkit or improving the workshop design and facilitation.

5.3. Opportunities for the GENS Codesign Toolkit and the Codesign Process

It emerged from our testing that the users considered it very important to obtain context-specific information. To a certain extent, this goes somewhat against our goal to develop a toolkit that is applicable in different contexts. A potential way to align these two requirements would be to add a set of context-specific layers to the core elements of the toolkit. These layers would, for example, provide country-specific information (e.g., the current situation in terms of gender mainstreaming, specific gender issues and current best practices). There could also be layers for each of the different types of informal urban settlements (e.g., following the classification provided by Smit et al. [44]).

In terms of the format, the current version of the toolkit is physical (i.e., paper-based). As a result, its use in a codesign process can take place only in a face-to-face mode. To overcome this drawback, there is the opportunity to develop the toolkit into a digital form. This would provide a range of benefits: (1) it would allow for individual online use (e.g., a single practitioner), as well as group use (e.g., multiple people within the same company or representatives from different energy stakeholders); (2) it would allow participation from people from different geographical areas; (3) it would allow users to digitally save data inputted in the different sections of the toolkit and share this data with other users; (4) it would allow simultaneous and asynchronous use from different users; (5) it would allow for embedding links to external resources (e.g., scientific papers and best practices); (6) it would allow for much wider dissemination of the toolkit; and finally, (7) it would allow for updates/improvements of the toolkit to be easily disseminated.

5.4. Threats for the GENS Codesign Toolkit and the Codesign Process

A key threat is that the contents of the toolkit might become obsolete. For example, some of the gender issues addressed by the toolkit might become irrelevant in the future, and at the same time, new issues might emerge. In addition, user practices change over time and the ethnographic data embedded in the toolkit might not reflect the future reality. Furthermore, new best practices and gender mainstreaming strategies might emerge, making some of the content of the toolkit not up-to-date. A potential way to overcome this problem could be to provide content updates to toolkit users. As discussed in the previous section, this could be more effective if the toolkit is in a digital format (e.g., by allowing users to download upgrades or new versions). In order to speed up the updating process, another strategy could be to allow users to input/suggest new content or to enable them to become "content generators" and develop their version of the toolkit (in an open-source and copyleft ethos).

Another threat to the toolkit is that its use currently requires the presence of an experienced facilitator (more on this in the next section). This is potentially problematic for two reasons: first, it could limit the use of the tool; second, if the toolkit is used without a facilitator (or with an inexperienced facilitator), the outcomes might be of low quality and the experience of users might not be positive.

5.5. The importance of Facilitation

We observed that the workshop design and the facilitation of the codesign process played an integral role in its success. The workshop must start with introductions to background information to make sure all participants are familiar with the terminology, context-specific data, existing issues and best practices before starting the codesign activity. The introductory part must be followed by a detailed presentation of the toolkit. The GENS codesign toolkit consists of six different components, thus it is critical to provide sufficient use instructions and support its application process step-by-step, ideally showing it on a screen. Furthermore, it is important to present alternative ways of using each tool to allow some degree of flexibility. Experienced facilitators must be present during the whole workshop. Supportive facilitation can help to address a lack of participant engagement and increase the number of ideas recorded on Post-It notes. A gendered approach to the workshop dynamics can help to ensure more gender-inclusive outcomes. Each group must include female and male participants, ensuring that all of them can express their opinion and share ideas despite their gender. As a result, there can be a need to have more representatives from each role of the energy sector to ensure an expertise and gender balance. Finally, the multistakeholder workshop can take more than 5 h 30 min to sufficiently complete the proposed codesign process. Each participating group could be provided with more copies of each tool.

5.6. Improvements to the Toolkit

The first evaluation round of the GENS codesign toolkit is complete. The codesign workshop helped to decide which changes and improvements are going to be implemented in the next version of the GENS codesign toolkit, including the facilitation and workshop design for the toolkit's use guidelines (Table 9).

The updated version will be ready to be used in the GENS Living Labs and other multistakeholder codesign activities. In fact, during the workshop, representatives from two private companies expressed their interest in applying the toolkit in their companies' work. Therefore, the new version of the toolkit can also be used by a single stakeholder independently. It will potentially be developed in a digital format that is enriched with links to additional data and information relevant to the context of the application.

Table 9. Insights gathered from the codesign workshop with suggestions for implementation in the next version of the GENS codesign toolkit.

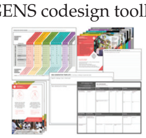
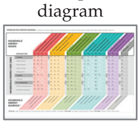
Toolkit's Elements	What Worked?	What Suggestions Emerged from the Workshop?	Will the Suggestion Be Included in the Next Version of the Toolkit?
All elements of the GENS codesign toolkit 	• Successfully integrates gender. • Supports energetic dialogue between the users. • Adaptable: the application can be modified by the users. • Supports data collection for a better understanding of the context. • Supports idea generation considering gender, energy and informal settlement aspects. • Supports generation of ideas, ranging from generic to original and elaborated. • Can be applied by private companies individually.	Include use guidelines in each of the tools.	Yes. Brief guidelines will be included: descriptions of each block of information and reading order of each of the tools.
		Increase the size of the prints.	Yes. The prints will be increased by one format size (i.e., from A3 to A2, etc.).
		Increase text size.	Yes. The text size will be increased as a result of the increased size of the prints.
		Translate the tools to local languages.	No. The English version was understood by all workshop participants. Images of case studies helped to improve comprehension.
Problem exploration diagram 	• Complete regarding content. • User-friendly layout. • Distinguishable colours. • Supports selection of diverse energy-related issues to be addressed.	Include local context-specific information with statistics, case studies and initiatives for each of the energy issues.	No. The diagram is an introductory tool that summarises the information included in the toolkit. More details are provided in the energy issue cards. The toolkit is made to be used in different contexts; thus, the included information includes different contexts. A digital version of the toolkit could include links to online databases that store relevant information from different contexts (e.g., UN Stats information on SDGs).
		Include sustainability implications.	No. The potential sustainability implications of using the toolkit will be summarised in the toolkit's use guidelines, together with other introductory material.

Table 9. *Cont.*

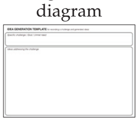
Toolkit's Elements	What Worked?	What Suggestions Emerged from the Workshop?	Will the Suggestion Be Included in the Next Version of the Toolkit?
Energy issues cards and additional data collection template 	• Complete regarding content. • Comprehensible language. • Case studies successfully complement the contents of the cards. • Case studies and idea generation questions successfully support idea generation.	Simplify the language.	Yes. Each sentence will be revised and potentially simplified to improve comprehension.
		Describe case studies by specifying implications for women and men.	Yes. More information on how the case studies address the needs of women and men will be included.
		Provide more information on roles of each gender.	Yes. More information on gender roles will be included in the description of causes and the questions for idea generation.
		Provide more context-specific case studies.	No. The toolkit is made to be used in different contexts; thus, the included information addresses different contexts.
		Provide the aspects of government involvement in the energy sector.	No. Government positions are described among the causes of some of the issues. However, government involvement varies from country to country, while the toolkit aims to include context-neutral information.
		Reduce information in the cards.	No. The aim of the energy issue cards is to provide in-depth information on the energy issues.
		Combine the energy issue card with the additional data collection template.	No. Being a separate tool, the additional data collection template can be used with the energy end-use cards too.
Energy end-use cards and additional data collection template 	• Complete regarding content. • Distinguishable colours. • Case studies successfully complement the contents of the cards. • Supports gender inclusion during group discussions and presentations of generated ideas. • Named as "the best part of the toolkit" by the users.	Simplify the language.	Yes. Each sentence will be revised and potentially simplified to improve comprehension.
		Include more gender considerations in the idea generation questions.	Yes. More considerations on gender roles will be included in the questions for idea generation.
		Include context-specific case studies.	No. The toolkit is made to be used in different contexts; thus, the included case studies will remain diverse.
Idea generation diagram 	• Complete regarding content. • Supports the categorisation of generated ideas.	Provide an explanation of how to select the idea(s) for further detailing.	Yes. Explanation of how to select "the most promising idea" will be included.
		Add colours.	No. The six different colours used in the toolkit are associated with different categories of household energy issues. Same or new colours will not be included in the diagram to avoid confusion.
		Include identification of the actor network as the next step.	No. The actor network is included in the energy innovation canvas, which is made to be applied in the next step.

Table 9. *Cont.*

Toolkit's Elements	What Worked?	What Suggestions Emerged from the Workshop?	Will the Suggestion Be Included in the Next Version of the Toolkit?
Energy innovation canvas 	• Complete regarding content. • User-friendly layout. • Effectively supports idea detailing.	Include sustainability and social issues.	Yes. Implications of environmental, social, and economic sustainability will be included in the *Outcomes* section.
		Make the canvas customisable depending on the idea.	No. However, use guidelines will specify that the canvas can be filled in any order, depending on specific ideas and that some sections can be left blank.
		Reduce repetitive sections (e.g., customer section is not always relevant)	
		Number a suggested order.	
		Add colours.	No. The six different colours used in the toolkit are associated with different categories of household energy issues. Same or new colours will not be included in the diagram to avoid confusion.
		Make an additional template for the problem statement.	No. However, the space dedicated to idea descriptions will be enlarged.
Facilitation and workshop design: GENS codesign toolkit's use guidelines	• The introductory presentations gave background information on gender, energy and informal urban settlements and helped with understanding the context. • The brainstorming principles were used during the idea generation. • Community members were crucial participants since they helped other stakeholders to better understand the energy context and informed the selection of issues to address.	An internal facilitator could join each group to facilitate participant engagement.	Yes. However, an internal facilitator must not influence the selection of energy issues, suggest their own ideas or get involved in idea detailing.
		Remind people to record ideas on the idea generation diagram.	
		Ensure equal representation of stakeholders from different sectors.	Yes. An equal number of women and men from public and private sectors must be involved in the codesign activity.
		Allocate more time for each stage of the codesign process.	Yes. Problem exploration, idea generation and idea detailing stages must be prolonged by at least 20 min each.
		Ensure all participants, regardless of gender, present their ideas.	Yes. A facilitator must include gender considerations while preparing for the workshop and during its implementation.
		Provide more copies per group of each tool.	Yes. At least two copies of each tool must be provided for each group.

6. Conclusions

In this paper, we present the first version of the GENS codesign toolkit that was made to support the design of energy innovations for informal urban settlements considering different issues, needs and capabilities of female and male energy users. The toolkit consists of six tools combined into our proposed codesign process. We tested the toolkit during a one-day codesign workshop in Nairobi, Kenya. The workshop simulated the activity that would potentially be implemented in the GENS Living Lab and was attended by representatives from private energy companies, Mathare informal settlement community members, energy researchers and a policymaker.

The toolkit expands know-how on the gender-energy nexus in urban areas and supports three Sustainable Development Goals (SDGs) [52]. In relation to SDG 5 'Gender equality' and SDG 7 'Affordable and clean energy', the toolkit supports energy companies in becoming more aware of gender-related energy issues and in developing solutions that can ensure energy security and, at the same time, address those issues. In addition, since the toolkit is specifically focused on informal urban settlements, it also supports *SDG 11: Sustainable cities and communities*, with a particular focus on SDG 11.1 related to access to basic services and upgrade of slums.

By evaluating the toolkit's completeness, usability and effectiveness, we identified that it successfully helped its users to learn about energy use in informal urban settlements and generate original ideas for energy innovations. We observed that the toolkit facilitated the dialogue and knowledge exchange between different stakeholders, which is critical for a fruitful codesign activity. The workshop also enabled us to identify the limitations of the toolkit, such as a lack of use guidelines and drawbacks of the layout, which are to be addressed in the next version of the toolkit. The testing provided a complete list of changes that need to be implemented in the second version of the toolkit.

In terms of value to the research community, this paper addresses the identified research gap by putting forwards a design toolkit that uniquely focuses on mainstreaming gender in energy projects, with an emphasis on idea generation and informal urban settlements. Researchers working on the gender–energy nexus can build upon these results, for example, by adopting the toolkit in their own projects or by identifying improvements to be made. The paper also provides insights on the methodological aspects to be taken into account to thoroughly test design toolkits. In terms of value to practice, the toolkit can provide energy companies, organisations and practitioners with a novel approach to integrating gender mainstreaming in energy projects for informal urban settlements. This toolkit specifically focuses on helping its users to identify gender-related energy issues and to facilitate idea generation processes. The final revised version of the GENS codesign toolkit must be seen as complementary to the current tools, handbooks and manuals on mainstreaming gender in energy projects.

Regarding the limitations of this research, two main aspects can be highlighted. First, the toolkit was tested only on one occasion. Although we were able to collect a rich set of data from different types of energy stakeholders, additional testing must be performed to strengthen the validation of the toolkit. Second, the toolkit was tested only with stakeholders from the same geographical area. It can therefore be questioned to what extent the results would change if the toolkit was tested in a different location. In order to address these limitations, we are planning to carry out additional testing in Groenheuwel (Paarl, South Africa) within the other GENS Living Lab. In addition, we are also planning to test the toolkit with individual companies/organisations to gather data on how this mode of use compares with use of the toolkit within a multi-stakeholder codesign workshop.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Appendix A

Table A1. A list of gender–energy nexus supports analysed to define established practices of gender mainstreaming in energy projects.

Reference	Type	Context	Link
Morris, E., Greene, J. and Healey, V.M. Blueprint Guide for Creating Gender-Sensitive Energy Policies. United States: N. p., 2019.	Guidebook	ECOWAS countries. Rural and urban.	https://www.nrel.gov/docs/fy19osti/73927.pdf (accessed on 20 May 2022)
ADB. Gender-Inclusive Approaches in the Energy Sector. Asian Development Bank, 2018.	Tipsheet	Low-income Asia. Rural.	https://www.adb.org/documents/tip-sheet-gender-inclusive-approaches-energy (accessed on 20 February 2022)
Nelson, S. and Kuriakose, A.T. Gender and Renewable Energy: Entry points for women's livelihoods and employment. Climate Investment Funds, 2017.	Guidebook	Developing countries worldwide. Rural and urban.	https://www.climateinvestmentfunds.org/sites/cif_enc/files/gender_and_re_digital.pdf (accessed on 20 February 2022)
DOE. Gender Toolkit for the Energy Sector. Manilla, Philippines, 2016.	Toolkit	The Philippines. Rural.	https://www.apec.org/docs/default-source/Publications/2017/5/Guidelines-to-Develop-Energy-Resiliency-in-APEC-Off-Grid-Areas/TOC/Annex-8-Philippines-DOE-Gender-Toolkit.pdf (accessed on 20 February 2022)
Hjorth, H., Vyzaki, M. and Bergman, M. Gender Mainstreaming in District Heating Projects in the Commonwealth of Independent States: A Toolkit. CIF, 2016	Toolkit	Ukraine and Kazakhstan.	https://www.climateinvestmentfunds.org/sites/default/files/gender_mainstreaming_in_district_heating_projects_-english.pdf (accessed on 20 February 2022)
Smith, G. and Shankar, A. Empowered Entrepreneur Training Handbook, Washington DC: Global Alliance for Clean Cookstoves, 2015.	Training manual	Developing countries worldwide. Rural and urban.	https://cleancooking.org/wp-content/uploads/2021/07/342-1.pdf (accessed on 20 February 2022)
O'Neil, D.; Renzy, D.; McDermott, A. and Atanassova, A. Building a Safer World: Toolkit for Integrating GBV Prevention and Response into USAID Energy and Infrastructure Projects. Rockville, MD: USAID's Advancing the Agenda of Gender Equality (ADVANTAGE), Task Order 3, 2015.	Guidebook	Developing countries worldwide. Urban.	https://www.usaid.gov/documents/1865/building-safer-world-toolkit-integrating-gbv-prevention-and-response (accessed on 20 February 2022)
ESMAP. Gender Equality and Energy: Tools and Guidance for Integrating Gender Issues into the Energy Sector. WBG, 2015.	Guidebook	Developing countries worldwide.	https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/Gender_Energy_M06.pdf (accessed on 20 February 2022)
SPC. Toolkit to Mainstream Gender into Energy & Climate Change Community Based Adaptation Projects in the Pacific, 2013.	Toolkit	The Pacific. Rural.	https://gendercc.net/fileadmin/inhalte/dokumente/4_Our_Work/past_projects/Pacific_Islands/Toolkit_to_Mainstream_Gender_into_Energy____Climate_Change_Community_Based_Adaptation_Projects_in_the_Pacific.pdf (accessed on 20 February 2022)
SPC. Gender Mainstreaming in Energy Projects in the Pacific, 2014	Training manual	The Pacific. Rural.	https://gendercc.net/fileadmin/inhalte/dokumente/4_Our_Work/past_projects/Pacific_Islands/Training_Manual_Gender_Mainstreaming_in_Energy_Projects_in_the_Pacific.pdf (accessed on 20 February 2022)

Table A1. *Cont.*

Reference	Type	Context	Link
UNIDO. Guide on gender mainstreaming: Energy and climate change projects. Vienna, 2014	Guidebook	Developing countries worldwide. Rural and urban.	https://www.unido.org/sites/default/files/2015-01/Guide_on_Gender_Mainstreaming_ECC_0.pdf (accessed on 20 February 2022)
Rojas, A. and Siles, J. Guide on Gender and Energy for Trainers and Managers of Public Policies and Projects, ENERGIA, OLADE and UICN, 2015	Training manual	Latin America. Rural and urban.	https://biblioteca.olade.org/opac-tmpl/Documentos/old0370.pdf (accessed on 20 February 2022)
Dutta, S. Gender Briefing Notes: Supporting active inclusion of women in energy and development projects. EUEI PDF, 2013	Briefing notes	Developing countries worldwide. Rural.	https://www.wame2030.org/files/catalogue/2016/12/gender_briefing_notes_1.pdf (accessed on 20 February 2022)
World Bank. Integrating Gender Considerations into Energy Operations. ESMAP knowledge series 014/13. Washington, DC. 2013.	Briefing notes	Africa. Rural.	https://openknowledge.worldbank.org/handle/10986/17479 (accessed on 20 February 2022)
CCA. Scaling Adoption of Clean Cooking Solutions through Women's Empowerment. Global Alliance for Clean Cookstoves, 2013.	Guidebook	Developing countries worldwide. Rural and urban.	https://www.empowerwomen.org/en/resources/documents/2013/11/scaling-adoption-of-clean-cooking-solutions-through-womens-empowerment-a-resource-guide?lang=en (accessed on 20 February 2022)
ADB. Gender Tool Kit: Energy. Going Beyond the Meter. Philippines, 2012	Guidebook	Asia. Rural.	https://www.adb.org/sites/default/files/institutional-document/33650/files/gender-toolkit-energy.pdf (accessed on 20 February 2022)
ENERGIA. Mainstreaming gender in the energy sector: Training manual. 2012	Training manual	Mozambique and Liberia. Rural.	https://www.energia.org/assets/2016/09/Mozambique-Manual-Mainstreaming-Gender-in-the-Energy-Sector-Training-Manual-final.pdf (accessed on 20 February 2022)
ENERGIA. Mainstreaming Gender in Energy Projects: A Practical Handbook. Practical action, 2011.	Handbook	Asia and Africa. Rural.	https://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/documents/Energia_Mainstreaming_gender_in_energy_projects_A_practical_Hand_book.pdf (accessed on 20 February 2022)
UNDP. Gender Mainstreaming: a Key Driver of Development in Environment & Energy. Energy & Environment Practice: Gender Mainstreaming Guidance Series, New York, 2007	Training manual	Developing countries worldwide. Rural.	https://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/Sustainable%20Energy/Gender_Mainstreaming_Training_Manual_2007.pdf (accessed on 20 February 2022)
UNDP. Gender and Energy for Sustainable Development: A Toolkit and Resource Guide. 2004	Toolkit and guidebook	Developing countries worldwide. Rural.	https://www.undp.org/publications/energy-and-gender-sustainable-development-toolkit-and-resource-guide (accessed on 20 February 2022)

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sustainability

Article

Aesthetics of Sustainability: Research on the Design Strategies for Emotionally Durable Visual Communication Design

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Abstract: Lately, most studies on sustainable design from the perspective of emotional durability focus on product design, particularly on exploring how do product functions direct consumers' emotional changes after the product is used, but overlook the significant impact of consumers' visual impression of the product on their judgment. Therefore, this paper aims at finding out how to maintain the emotionally durable connection between consumers and products with the help of visual communication design so as to provide guidance for prolonging the service life of products and reducing the waste and consumption of resources. Based on literature reviews on sustainable design, visual communication design, and emotionally durable design, this paper firstly adopted the case study method to analyze more than 85 high-quality design practice cases and put forward preliminary design strategies. The behavior research method was then applied to analyze the consumer behavior involved in the preliminary design strategies, and those design strategies were upgraded according to the analysis results. Based on the above analysis and research work, this paper proposed six design strategies to improve the emotional durability of visual communication design, namely, Enjoyment, Functionality, Narrativity, Symbolism, Interaction, and Innovation. In the area of sustainability, the design strategies proposed in this paper provide a new design mode for emotionally durable visual communication design and make products to be more acceptable to consumers and long-term holding. Emotionally durable visual communication design can influence consumers' aesthetics and lead consumers' behavior toward more sustainable use of products.

Keywords: sustainability; sustainable design; emotionally durable design; visual communication design; design strategy

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1. Introduction

People may discard items that can still work for various reasons, but only a few people feel that the service life of these discarded items should last longer [1–3]. According to past data analysis, the life of discarded items was approximately two-thirds of their reasonable service life. For small electrical appliances specifically, their service life was roughly five years shorter than their reasonable life [3]. From the perspective of sustainability, such a high product turnover rate should be discouraged because it would result in waste and more resource consumption [4]. Even if these discarded items were made from degradable or renewable materials, excessive environmental pollution and waste could not be avoided. As concluded from past research, it is found that most people tend to frequently replace their innovative products, such as cell phones and electric appliances [3], since the decorative features of these products are changed every year [5] (p. 86). From the perspective of design, these phenomena can be traced back to the negligence of some designers since they were not profoundly aware of these sustainability issues. To overcome these issues, scholars and designers attempted to find possible and feasible measures both from theoretical and practical aspects to extend the life of products.

The concept of sustainable development originates from a report titled "Our Common Future" published by the World Commission on Environment and Development in 1987. It was defined in the report that "sustainable development" should "ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" [6] (p. 8). As Ben Highmore said, it was acknowledged that global warming and climate change were partially resulted from various design processes, design values, and design products [7] (p. 1). In the second half of the 20th century, Victor Papanek linked design with the environment for the first time, which criticized the design industry at that time and put forward the opinion that designers should take responsibility for the ecology and society [5]. Furthermore, the Green design [8,9], the Ecodesign [10–12], and other design concepts aiming at reducing the impact of products on the ecological environment through design were proposed subsequently. Though the Green design and the Ecodesign paid attention to the effects of products on the environment, they lost sight of society-dimensional sustainability. As a result, they did not significantly affect environmental improvement [13,14]. In April 2009, The Society of Graphic Designers of Canada (GDC) gave a specific definition of "sustainable communication design" for the first time at its annual conference. That is, "sustainable communication design is the application of sustainable principles to communication design practice. Practitioners consider the full life cycle of products and services, and commit to strategies, processes and materials that value environmental, cultural, social and economic responsibility [15]". The proposal of this definition indicates that the concept of sustainability has begun to be developed in the field of visual communication design, and the role of visual communication designers in society would change significantly. On the other hand, it also reveals that visual communication designers still do not have a clear solution to the problem of sustainability.

In 2015, the United Nations General Assembly (UNGA) established 17 Sustainable Development Goals (SDGs) [16], which remind designers that they are expected to make contributions to sustainability in social, environmental, economic, and cultural dimensions. Afterward, the World Design Organization (WDO), the World Packaging Organization (WPO), the International Council of Design (ICoD), the Society of Graphic Designers of Canada, the American Institute of Graphic Arts (AIGA), the British Fashion Council (BFC), the Council of Fashion Designers of America (CFDA), the Industrial Designers Society of America (IDSA), and other international design organizations gave more specific explanations to the goal of sustainable design through design practices, design competition, design forum, and other design activities.

With the goal of sustainable design being continuously embodied, the design industry has gradually paid more and more attention to consumers' behavior [17–20], the interaction between consumers and products [21], healthy lifestyle [22], and other aspects in addition to the ecological environment. As a response to sustainability issues in the design theory and design practices, sustainable design is implemented, which reduces the negative impact of products on the economy, society, culture, and the environment, while the extent to which improves the consumers' personal responsibility, quality of life, physical and mental health, and the like. These factors were considered as the criteria for sustainable design. Over the past 33 years since the concept of sustainability was put forward, scholars and designers have increasingly applied the concept of sustainable design in different aspects of design research and design practices, such as design innovation on product's spatial, technological, and social relevance [23–25], the extension of product's lifecycle [2,4,26–30], simplification of sustainable behavior [31] (pp. 120–121), brand sustainability [10,32–36], sustainable packaging [37–44], and visualization of material sustainability [31] (pp. 26–27).

With the development of sustainable design, scholars realized that emotion plays a fundamental role in various types of design works [29,30,45–48]. Research on emotion-centric sustainable design began in 1999 [49] and was a relatively new but rapidly growing category of sustainable design research. It aimed at integrating salient themes of emotional experience into the design industry. Research on emotion-centric sustainable design covers several subcategories of sustainable design, such as material culture design [50,51], product design [4,26,29,30,45,50,52–58], brand marketing design [59–61], consumer experience centred design [46,62–65], costume design [66–68], etc. It was commonly found that when people assign specific values to products for emotional reasons, they would use these products more carefully because they expect to keep these products for a longer period. For instance, people may get a product repaired when it is damaged, or use it more carefully so that the product is less likely to be damaged. Past research found that this emotional connection between consumers and products can be achieved through a sustainable design approach called the "emotionally durable design". It means products are designed to increase the durability of the relationships between consumers and products, to extend the life cycle of products, and further reduce the consumption and waste of natural resources [29,30,45,52]. In the research and practices of emotionally durable design, most scholars and designers focused on the product design itself, such as the product's material, shape, and user experience. However, most scholars and designers have neglected that people's visual impression of the product greatly impacts people's judgment of this product [48,69].

A significant recent research result of including emotional durability into product design practices is the emotionally durable design framework proposed by Haines-Gadd, Chapman, Lloyd, Mason, and Aliakseyeu in 2018 [45]. This design framework specifically includes nine subjects, representing nine design factors that designers need to pay attention to in design practice, including Relationships, Narratives, Identity, Imagination, Conversations, Consciousness, Integrity, Materiality, and Evolvability [45] (pp. 14–15). Furthermore, Chapman [29,30], Burcikova [67], Van Krieken et al. [52], Haug [26], Schifferstein et al. [4], Richins [53], Kleine et al. [54], Mugge et al. [28], Agost et al. [70], Csikszentmihalyi et al. [50], Wu et al. [71], BERG et al. [72], Huang et al. [73], Seva [74], and other scholars also proposed design strategies that can guide designers to apply the concept of emotional durability in product design and clothing design practices. In fact, consumers would judge some unique features of a product, such as physical durability, spiritual attributes, and symbolism, by its appearance. Therefore, research on visual communication design should not be related to the aesthetic aspect only. However, research that links emotional durability with visual attributes was rarely reported. Only a few scholars, such as Schifferstein [4], Cupchik [75], Haug [26], Mugge [28], Walker [69], McDonagh [76], and Norman [77] et al., included the appearance in the contributing factors of emotional attachment and believed that visual sensory experience could affect the level of emotional attachment. Hence, it is found that past research seldomly focused on the relationship between emotionally durable design and visual communication design, which leads to the research topic of this paper.

This paper will focus on enhancing the emotional durability of products before use through visual communication design. It is believed that the emotionally durable visual communication design can be construed as an interpretive design. In other words, designers tend to analyze consumers' emotions including their personal experiences, moods, and desires and attempt to convey them accurately. Through literature review, analysis of past visual communication design practices, and investigation of the consumer market, this paper will put forward a set of design strategies for visual communication design and discuss the potential impacts of these design strategies on visual communication design practices. This set of design strategies comprises six parts, namely, enjoyment, functionality, narrativity, symbolism, interaction, and innovation. These strategies will guide designers to strengthen consumers' emotional attachment to products through design, achieve sustainable use of products, and reduce waste and unnecessary consumption.

2. Methodology

This paper aims at establishing a set of design strategies to assist designers in improving the emotional durability of their visual communication design works. At present, the methods for the research on the relationship between products and emotional attachment mostly rely on questionnaires. Research by Niinimäki et al. pointed out that questionnaires can collect consumers' responses, but they were far from enough to gain insights into the details of consumers' emotional changes [78]. Alternatively, Gupchik proposed a formula to analyze the origin of emotion, which is, "COGNITIVE MEANING + AROUSAL = EMOTION". It combined British empiricism and behaviorism [75] showing that a composite research method may be a better choice. In addition, Chapman [29,30,79,80], Haug [26], Norman [77], Wu et al. [71], Van Krieken et al. [52], Desmet et al. [49], Ceschin et al. [23], Haines-Gadd et al. [45], Cupchik [75], Tseng et al. [81], Fossdal et al. [82], and Saraiva [83], also adopted qualitative research methods to study the emotionally durable design. The complex relationship between consumers and designed products became easy to understand in their works. Therefore, a composite qualitative research method consisting of literature review, case studies, and behavior analysis will be used to establish emotionally durable visual communication design strategies in terms of design theories, design practices, and consumers' emotional experiences. Figure 1 shows the research methods and processes adopted in this paper.

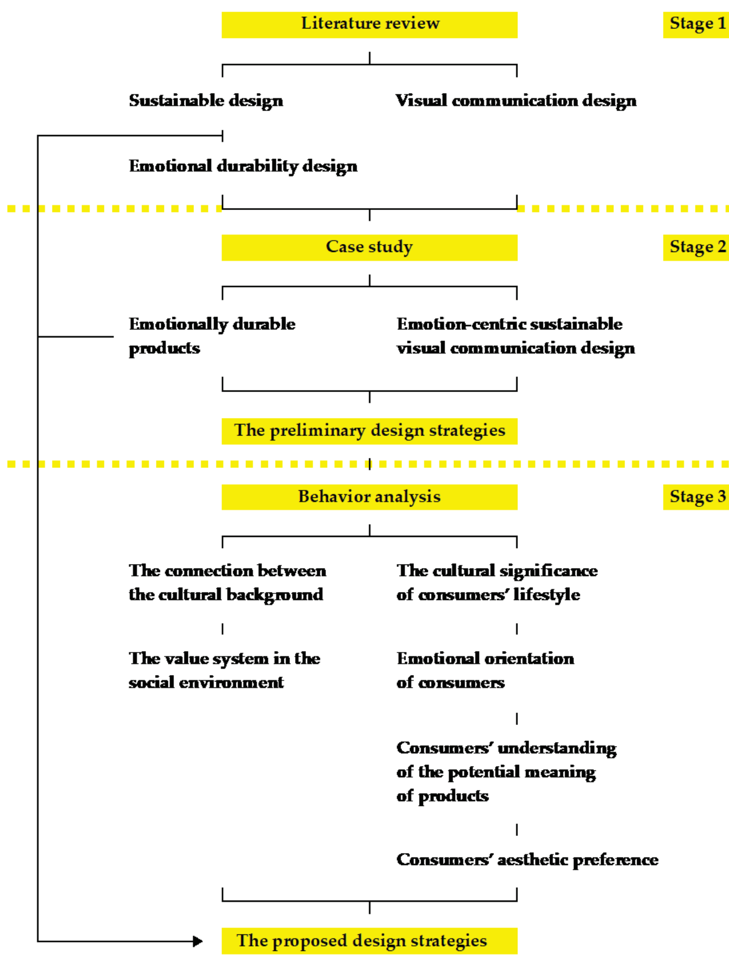

Figure 1. Research methods and processes.

Firstly, this paper reviews literature related to the sustainable design theory, emotionally durable design theory, and visual communication design theory. This part of the work has three emphases. The first emphasis aims to understand the internal driving factors of consumers' emotional attachment to products and how these factors affect them. Special attention will be paid to distinguishing these factors according to the persistence of consumers' emotional responses. The second emphasis is to determine which design methods can be used by designers to increase consumers' emotional attachment to products at the theoretical level, and to judge whether these design methods can be selected according to different design demands. The third emphasis is to analyze those proposed design strategies by studying their targeting practical problems and find out whether there are research gaps.

Secondly, this paper adopts the case study method to analyze more than 85 high-quality design practice cases. The research content concerning design practices includes an analysis of design practices on emotionally durable products and emotion-centric sustainable visual communication design practices. It should be noted that the visual communication design practices stated here involve the design of product shapes, materials, colors, semiotics meaning of packages, the visual image of brands, product advertisements, online shopping interfaces, and forms of showcasing in stores. There are three emphases in this part of the research. The authors firstly put weight on analyzing practical design cases of daily necessities to understand how designers give new meanings to these products. The second aim is to analyze similarities and differences between the design methods used in design cases and those proposed in theories. By combining the results of the above two research emphases, the authors thirdly propose preliminary design strategies. These preliminary design strategies will be refined afterward, and the analysis results of case studies will be one of the bases to verify the feasibility of these design strategies.

Thirdly, this paper uses the behavior research method to analyze the consumer behaviour described in these preliminary design strategies. As stated by Nigel Whiteley, the research on culture is also the research on design because the study of culture helps scholars to examine design on the basis of social and cultural context [84]. In specific, the research work in this paper focuses on the connection between the cultural background and emotional orientation of consumers, the cultural significance of consumers' lifestyle, the value system in the social environment, consumers' understanding of the potential meanings of products, consumers' aesthetic preference, etc.

Finally, this paper integrates the research results of the three parts mentioned above to improve design strategies.

3. Establishment of Design Strategies

Visual communication designers play essential roles in controlling the deterioration of the ecological environment. Once their design works are put into mass production, the outcome of their impacts on social culture and the ecological environment is fixed [31] (p. 27). As the visual communication design industry pays more and more attention to sustainability, designers are expected to consider how to enhance the sustainability of products during the entire consumption process [29]. It should be clearly stressed that the term "consumption" refers not only to purchase behaviour but also to the formulation of routines and rituals for using products or services. Consumers may make specific modifications to some attributes of the products, which involve selection, purchasing, using, maintenance, repairing, disposal, and recycling of any product or service. The design strategies proposed in this paper are developed in the context of research on visual communication design. They will focus on guiding design to help consumers fulfill needs without consuming additional resources while satisfying their needs.

Past research demonstrated that emotional attachment is correlated with self-extension. Specifically, when people think that a product is irreplaceable emotionally, they may regard it as an integral part of themselves [4,54,85–88]. Greenwald once proposed that people's self-schema may be classified into four aspects: the diffuse self, the private self, the public self, and the collective self [89]. It was similar to Jordan's four-type pleasures theory: physio-pleasure, psycho-pleasure, socio-pleasure, and ideo-pleasure [58]. These two theories provide this paper with variables that can influence the degree of people's emotional attachment to products. This paper proposes a design strategy system composed of six design strategies. As consumers' emotional attachment to different types of products may vary, each strategy contains two or three more supplementary strategies to guide designers in a more precise manner in practices. Table 1 lists the six design strategies and their supplements proposed in this paper.

To more intuitively show the implementation ability of these design strategies, several examples of good design practices relevant to each design strategy are listed in the third column of Table 1. Guided by any individual or a combination of these design strategies, visual communication design is expected to develop towards a more emotionally durable direction and trigger the potential for more sustainable use of products. Figure 2 shows the relationship between six design strategies and the fourteen corresponding supplements. In the following paragraphs, each design strategy will be specifically explained. The effects these design strategies may pose or have posed on visual communication design practices will be discussed.

Table 1. Design strategies for emotionally durable visual communication design.

Design Strategies	Supplements	Design Cases
1. Enjoyment [4,26,49,58,71,73,74,90]	1a. Indicates the pleasure of the product in use [4,68,90–93].	• Rooster Teapot (Michael Graves) • "Ready to be loved again" (M&C Saatchi) • News of the Wooled Introduction to Knitting (Gwyn M. Lewis) • Emotional Lighting (UMID) • The "B-set" (Hella Jongerius) • Humidifier (Kenya Hara) • Smile Stool (Jaime Hayon)
	1b. Provide consumers with interesting and unexpected interactions and discoveries during use [29,71,72,74,94,95].	• Google Doodles (Google Doodlers) • Humidifier H5 (Second White) • Mental-Soothing Device (Shin Chen, Hongting Ye) • Humidifier (Kenya Hara)
2. Functionality [4,26,27,49,71]	2a. Show the practical functions of products and reflect their reliable quality [4,49,52,71,96–98].	• Apple Ads (Apple) • "Ready to be loved again" (M&C Saatchi) • HANDVÄRK Mantle (Iskos-Berlin) • Umeda Hospital signage system (Kenya Hara, Yukie Inoue, Taichiro Takeo, Nozomi Morisada)
	2b. Show products' real and specific functions [29,30,45,49,98,99].	• The sustainability scorecard (Celery Design) • Harman Kardon SoundSticks (Harman Kardon) • People People Wireless Transparent Speaker • "Bunaco" (Nendo)
3. Narrativity [4,30,45,71,73]	3a. Show that products can be used as gifts for holidays, anniversaries, and other special days [4,30,45,54,73,74,100].	• "Ready to be loved again" (M&C Saatchi) • Starbucks' Holiday Cup (Starbucks) • Lego Brick Headz Valentine's Puppy Building Kit (Lego)
	3b. Create a nostalgic or retro feeling with a visual image that can reflect the past [52,71,81,101,102].	• Marshall speakers (Marshall) • Volkswagen New Beetle • Beyond Retro Label (Beyond Retro) • Woo-bi desk lamp (Jaekyoung Oh) • Gravity Controlled Clock (Stylepie) • Apple Ads (Apple) • New Chinese Toys (Made in Nature) • New Chinese Goods (Made in Nature) • MINI Cooper (BMW) • MUJI wall-mounted CD Player (Naoto Fukasawa) • Mom'n Baby (Matthieu Manche) • ReCoil (Brodie Neill)

Table 1. *Cont.*

Design Strategies	Supplements	Design Cases
	3c. Tell an interesting and continuous story [29,45,52,72,81,103].	• PUMA shoes (Emma Whiting) • Stain tablecloth (Seb Oddi) • "Stain" teacups (Bethan Laura Wood) • The "Hawley side table" (The Egg Collective)
4. Symbolism [26,27,52,104]	4a. Symbolize personal or social identities that consumers expect, and promote consumers' self-identification or a sense of belonging to their social groups [4,26,27,52–54,58,68,71,73,100,105–107].	• "I'm Not A Plastic Bag" (Anya Hindmarch) • GOGO Lamp (Wang Chih Hung) • Adidas football shirt (Adidas) • Brooks Green Silence (Brooks) • "I Am A Plastic Bag" (Anya Hindmarch) • "World's first paper razor" (Kai)
	4b. Embody the symbolism of cultural value [26,27,73,74,108,109].	• Helvetica typeface (Eduard Hoffmann) • "I Love NY" logo (Milton Glaser) • Hyouri (Nendo) • Vlisco Recycled Carpet (Vlisco) • New Chinese Toys (Made in Nature) • New Chinese Goods (Made in Nature)
5. Interaction [45,49,52]	5a. Create interesting interactions between consumers and products and between consumers [29,45,49].	• Pig line ball (LU YU) • Agrafeuse Bleu-Vert (Papier Tigre) • Non-temporary ceramics (Hella Jongerius) • News of the Wooled Introduction To Knitting (Gwyn M. Lewis) • Gel Remote Control (Panasonic Design Company) • Tadpole Coasters (Shin Sobue) • High Five with a Hand from the Future—Gel Doorknob (Toyo Ito) • Mom'n Baby (Matthieu Manche) • 800 dots—Paperback Cover (Masayo Ave) • Hyouri (Nendo)
	5b. Enable consumers to reflect interactivity by assigning products with personality [29,45,52,57,70,110–113].	• "Swatch X You" (Swatch) • MUJI Jute My Bag (MUJI) • Lego • Pandora Charm Bracelets (Pandora) • Oroog • Apple iPhone 13 (Apple) • Puzzleware (Almaborealis)
6. Innovation [67,74]	6a. Create new usage routines, rituals, and experiences for products (or services), and modify some attributes of products specifically or symbolically [45,110,114,115].	• The Juicy Salif Lemon Squeezer (Phillippe Starck) • Humidifier H5 (Second White) • Interface's leasing model (Interface) • News of the Wooled Introduction to Knitting (Gwyn M. Lewis) • Refillable bottles (Emanuele Pizzolorusso)
	6b. Create more uses for the products without additional components [45,55,78,98,100,116].	• "Foldschool" (Nicola Enrico Stäubli) • Jingle Bank (Hellen Lee) • Peppa Pig Milk Cookies • "Signature" (Butter by Nadia) • Origami Wrap (Ilovehandles) • Eco Warrior Bag (Rezon) • Straws (Benjamin Hubert) • Lucirmás: pure bottle (Lucia Bruni)
	6c. Leave room for design innovation [29,45,117,118].	• Swatch • LIFEWTR's Art Beyond Borders series (Athier, Ebtisam Abdulaziz, Basmah) • Rodin Mermaid Collection (Donald Robertson) • Harry's Razors (Tom Dixon) • Lego's "House of Dots" (Camille Walala) • HONOR Magic Watch 2 (Jacky Tsai, George Greaves, Wang DongLing, Giovanni Ozzola) • Louis Vuitton Masters Collection (Louis Vuitton)

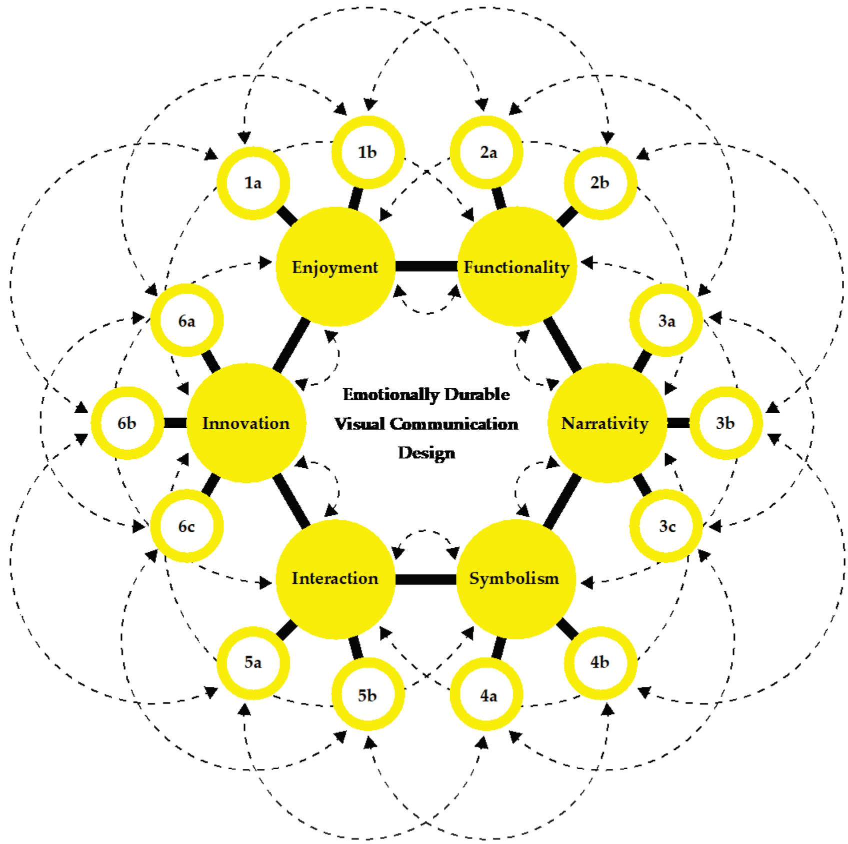

Figure 2. Design strategies for emotionally durable visual communication design (Source: Drawing in this study).

3.1. Enjoyment

The "enjoyment" design strategy [4,26,49,58,71,73,74,90] is proposed to improve consumers' attachment to the products by enhancing the consumers' enjoyment before or during the use of products through design. Past research shows that consumers' emotions toward products may already exist before purchasing these products [4,29,119,120]. Before consumers plan to purchase the product, they may have established a certain connection with the product through advertisements, window showcasing, web pages, and other channels. In addition, when consumers cannot afford the desired product, they may fantasize many times about owning the product or using the product. Therefore, the first supplement (1a) reminds designers to focus on enhancing consumers' emotional attachment before the product is purchased and extend the emotional attachment as long as possible after the product is purchased [4,68,90–93]. Specifically, designers can improve products' appearance, color, advertising, packaging, exhibition, website, and other aspects of aesthetic design, or can strengthen consumers' loyalty to a brand by presenting its core values. Norman criticized the Rooster Teapot designed by Michael Graves as he thought that this teapot was showy and useful. However, he was immediately rebutted by a consumer who owned this teapot, who said, "Every time when I wake up in the morning and stumble across the kitchen to make my cup of tea, it always makes me smile." [77] (p. 7). It is clear that an aesthetic appearance can indeed make consumers feel attached to the product and affect their behavior. In addition, other design works such as the Smile

Stool designed by Jaime Hayon, the Humidifier designed by Kenya Hara, and the "B-set" designed by Hella Jongerius also follow the Enjoyment (1a) design strategy.

As the "enjoyment" design strategy highlights the "private self" aspect of the self-schema, it embodies the pursuit of "psycho-pleasure". The second supplementary strategy (1b) reminds designers to take on the role of consumers, to pay attention to the potential delicate emotional needs and changes of consumers in the process of use, and to include interesting interactions or discoveries, that are not available in other similar competing products, during using the product [29,71,72,74,94,95]. Thus, consumers can form a more profound attachment to the product by applying these two supplements [121]. In Norman's research, the product experiences from more than 150 netizens were collected. One of the netizens said that he had a commemorative cup, and this cup was beautiful in appearance, and its decoration could only be seen when the cup was filled with hot drinks (the cup is covered with a layer of thermal glaze), and the user can perceive if the coffee becomes cool at a glance. So, he loved it very much and used it as his special coffee cup [77] (p. 216). Most products cannot maintain an enduring relationship with consumers [29] (p. 20), but the statement of this netizen indicates that he enjoyed the interesting interactions while using the cup due to its unique visual design. The relationship between him and the product became more intimate.

The Second White is a Korean design studio dedicated to designing daily essentials. In 2019, the Second White designed a humidifier named "Humidifier H5" which integrated the Enjoyment (1b) and the Innovation (6a) design strategy. As the Second White stated, everyone has fond memories of sunrises and sunsets. Therefore, this studio combined the functions of the humidifier with the image of sunrise and sunset, so that consumers can recall his/her emotions, such as anticipation, hope, excitement and calm, while using the humidifier [122]. In addition, the sun-shaped steam nozzle in the humidifier was designed to be removable, which allows consumers to place it in any containers filled with water. Humidifiers with such a design improve the humidification function of the humidifier and strengthen the concept of sunrise and sunset. With the increas in the times the humidifier is used, emotions experienced by consumers in the process of using the humidifier will be repeated and strengthened. These emotions are not short-term or reflexive, but stable and durable. Similar examples are available, such as the Mental-Soothing Device designed by Sin Chen and Hongting Ye, and the Humidifier designed by Kenya Hara.

3.2. Functionality

The "functionality" design strategy [4,26,27,49,71] reminds designers to show consumers the real and practical functions of products, thus strengthening consumers' trust, and heightening consumers' attachment to the product. This design strategy is proposed in a realistic context that the contemporary economic system works based on rapid product replacement and plans for obsolescence [78]. In other words, production and consumption are generally in an unsustainable state, that is, low product price tempts consumers to make fast and unsustainable consumption, and most products are not designed for durable use. However, by tracing back to the origin of design history, we can easily find that the original intention of product design is to achieve durability, ease of use and easy mass production [57,108–121,123–125]. Therefore, the first supplementary strategy (2a) is proposed to remind designers to show the reliable quality of products by presenting their practical functions through visual communication design [4,49,52,71,96–98]. For example, designers can design advertisements and packages to show that the product can be used by several generations [45].

A typical practical design case that follows the Functionality design strategy is the Umeda Hospital signage system designed by Kenya Hara, Yukie Inoue, Taichiro Takeoand Nozomi Morisada. Kenya Hara et al. deliberately chose white cotton cloth as the material for the hospital's guidance system, though most designers would commonly choose the acrylic plate, foundry resin, photopolymer, and other materials which are resistant to dirt but not environmentally friendly. All information is printed on white cotton cloth, which is secured to the corner of stairs, roof, and other display areas with supports. The white cotton cloth, which is easy to disassemble and not resistant to dirt, shows patients that the hospital is clean and committed to the strictest standards of hygiene at all times.

The second supplementary strategy (2b) is proposed to advise designers to present the functions of products in detail by visual communication design to gain consumers' trust [29,30,45,98,99]. It is necessary to have a detailed product description [98] that acts as an essential "intermediary" role in helping people understand and use the product in an ideal way as predefined by designers. At present, many design works can provide consumers with a clear and intuitive understanding of products by visually displaying the internal structure of products. The transparency of products is increased in terms of physical information presented.

For example, the Harman Kardon SoundSticks and the People people Wireless Transparent Speaker with visible internal structures, a watch with a transparent dial, a glass steamer, a sustainable scorecard [31] (p. 27), a toothbrush with its service life specified on the package, and a printer with double-sided copying function indicated on its body, and so on. The above-mentioned design works enhance the participation of consumers in the use process and strengthen the trust of consumers in the products through special visual communication design. It should be noted that as an excessive emphasis on the physical durability of a product can easily weaken people's attachment to the product [97], the "functionality" design strategy should serve as a basic strategy combined with other design strategies.

3.3. Narrativity

The "narrativity" design strategy [4,30,45,71,73,105] aims at strengthening consumers' attachment to the products by telling stories between the products and the consumers via design. With the first supplementary strategy (3a) in mind, designers are expected to guide consumers to obtain products in specific manners attachment is more likely to develop. For example, products can be given as gifts for holidays, anniversaries, and special days [4,30,45,54,73,74,100]. The memory of the first contact with the product affects a consumer's initial feeling about the product, and may further affect the mood during owning the product [4] (p. 4). When products are obtained as gifts, people may transfer their emotions and memories on givers to the products [126]—even if these products undergo degraded functions, faded appearance, and obsolete techniques during use, users may still prefer to repair rather than to discard the products. For example, the bone china tea sets as wedding gifts are usually properly preserved and are always packaged as holiday gifts that are more likely to be purchased. During the use of these products, the status of "gift" endows products with the power of developing attachment, thus making products more acceptable and even highly tolerable to consumers. When the first supplement of the "narrativity" strategy is combined with the first supplementary strategy of the "enjoyment" design strategy, it will provide consumers with a deeper and more provocative emotional experience due to the combination of visual impact and rich content brought by design.

For instance, M&C Saatchi Group combined narrativity (3a), enjoyment (1a), and functionality (2a) in design practice. It made a propaganda poster for the Christmas campaign "Ready to Be Loved Again" jointly launched by H&T Pawnbrokers and M&C Saatchi. It encourages people to give second-hand jewelry that can be used by generations as Christmas gifts to friends and relatives. As Cindy McCooey, the director of marketing at H&T Pawnbrokers, said, "We know that pre-loved gifts have grown in popularity in recent times, with more and more people choosing to buy sustainably and looking for gifts that can't be found elsewhere on the high street. This campaign taps into this trend and highlights the benefits of buying pre-loved jewelery as a unique Gift" [127]. This advertisement made people realize that buying gifts from pawnshops could be unique and romantic. People could be fascinated by the way they buy gifts and the presents obtained through such a unique route. Besides this, the Starbucks' Holiday Cup and the

Lego BrickHeadz Valentine's Puppy Building Kit are two typical design cases considering the Narrativity (3a) design strategy.

With the second supplementary strategy (3b) in mind, designers are expected to create a feeling of nostalgia or retro [52,71,101,102] by employing visual images that reflect the past. Past research findings show that nostalgic design provides aesthetic and emotional appeal and induces consumers to develop complicated mixed emotions such as warmth, happiness, historical emotions, longing, sadness, and comfort. Consumers' satisfaction with products thus can be significantly improved [128–133]. Designers may provide tangible metaphors to evoke the consumers' good memories of the old days using some nostalgic decorative patterns, shapes, materials, slogans, colors, and display methods through brand visual images, advertisements, packages, exhibitions, etc.

For example, the MINI Cooper car launched by BMW in 2001 was actually a new version of the Morris Mini-Minor car (as shown in Figure 3) designed by Alec Issigonis in 1959. The MINI Cooper retained the original round headlights, uniquely shaped roof, hexagonal grille, angular chassis, and vibrant colors of the Morris Mini-Minor. In addition, the modern materials used in the MINI Cooper, the shape of the instrument panel, and the style of the interior doors also enhanced the retro feel of the car, thus considerably triggering the nostalgia of consumers. Some critics directly suggested that consumers should ignore the disadvantages of MINI [77] (p. 7). Moreover, the New York Times reported in 2002 that: "Whatever one may think of the MINI Cooper's dynamic attributes, which range from very good to marginal, it is fair to say that almost no new vehicle in recent memory has provoked more smiles." [134]. Similar to the MINI Cooper, the Volkswagen New Beetle (appearance and color, etc.), the Woo-bi desk lamp (appearance and color), the Gravity Controlled Clock (shape and color), the MUJI wall-mounted CD Player (appearance and usage), the Apple iPhone (nostalgic advertising, flat interface, etc.), and the Marshall Audio (shape and color, etc.) also adopt nostalgic visual images to win consumers' emotional attachment.

Figure 3. Alec Issigonis photographed at Austin, Longbridge standing next to the first Mini (621AOK) and a new 1965 Morris Mini-Minor Deluxe (Source and Author: Birmingham Museums Trust).

With the third supplementary strategy (3c) in mind, the designers can strengthen consumers' attachment to a product by telling and narrating, interesting and continuous stories with their design works [29,45,52,72,103]. Specifically, designers should maintain the interaction between consumers and products with the help of design as the medium, and further enrich the relationship between consumers and products through the image narration of visual communication design. For instance, Emma Whiting designed a pair of emotionally durable shoes for PUMA in an attempt to extend the life of the shoe without increasing the production cost. These shoes feature a special coating for printing patterns on the vamp. The traces of wear and dirt on the vamp are no longer a sign of loss of material value, but become the base color of the vamp that highlights the pattern with the elapse of time. The aging process can also strengthen rather than weaken a certain experience [79] (p. 144). These patterns and signs of wear and tear cause consumers to recall stories that happened in the use of shoes, thus increase the uniqueness of shoes, and also enhance consumers' attachment to shoes. The "Stain" teacups designed by Bethan Laura Wood also used the Narrativity (3a) design strategy [135]. The inner surface of "Stain" teacups was specially treated. The more consumers use the cup, the more they scratch and stain the cup, and the clearer the design pattern on the inner surface of the cup will be. As time went on, consumers would own cups that hold memories and fit their drinking styles. Similar examples include the Stain Tablecloth designed by Seb Oddi and the "Hawley Side Table" designed by The Egg Collective.

3.4. Symbolism

The "symbolism" design strategy [26,27,52,104] is to enhance consumers' attachment to products by reflecting the symbolic identity or value expected by consumers through design. With the first supplementary strategy (4a) in mind, designers are advised to exhibit personal or social identities expected by consumers through product appearance design, thus promoting consumers to form a sense of self-identity or belonging to a group [4,26,27,52–54,58,68,71,100,105–107]. People need a sense of belonging and prefer products that symbolize their belonging to a particular group or organization [105] (p. 13). A large number of products in our daily lives that are emotionally and psychologically easier for consumers to use due to the symbolic meaning given by designers. There are several typical examples, such as commemorative football shirts emblazoned with the team's logo (symbolizing that the consumer might be a fan of the team), designer-brand fashion furniture (symbolizing consumers' personal and aesthetic self-identity), a lamp designed to be like a dog (symbolizing the sense of belonging that family brings) [136], cups in International Klein Blue (symbolizing consumers' solitude and pure personalities), shoes made from recycled materials (symbolizing consumers' belief in sustainability), etc.

With the second supplementary strategy (4b) in mind, designers are expected to design products to reflect the symbolism of specific cultural values to strengthen consumers' attachment to the product [26,27,73,74,108,109]. The concept of "self" mentioned in the first supplementary strategy of the "symbolism" design strategy above intrinsically has regional cultural characteristics. However, the concept of "self" emphasizes consumers' relationship to a particular product sample, while the concept of culture focuses on communication. Therefore, this paper deems cultural values as a separate supplementary strategy. With that in mind, designers are expected to pay attention to the emotional attachment brought by the communicative value of the design embodied in cultural exchanges in different regions. For example, the Helvetica typeface (as shown in Figure 4) designed by Eduard Hoffmann for the Swiss market was also widely used in the logos of brands worldwide, symbolizing the company's modernist philosophy [137,138]; The "I Love NY" logo (as shown in Figure 5) designed by Milton Glaser, symbolizing the spread of American visual culture, made people fall in love with New York City again.

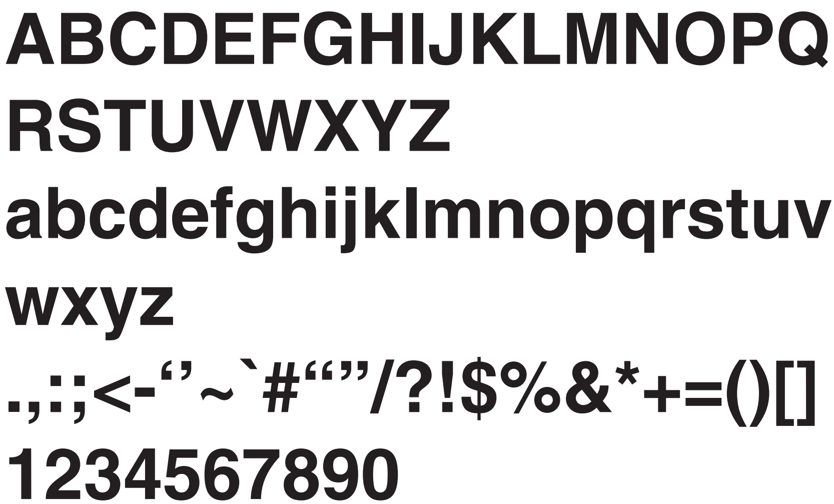

Figure 4. The Helvetica typeface (Source: Available in personal computer operating systems).

Figure 5. “I Love NY” by Milton Glaser (picture by Museum of Modern Art, Available online: http://www.moma.org, accessed on 25 January 2022).

3.5. Interaction

The “interaction” design strategy [45,49,52] is intended to create interactions between consumers and between consumers and products by the mean of design, thereby heightening the consumers’ attachment to products. The first supplementary strategy (5a) suggests that designers should create consumer–product and inter-consumer interactions by adding interest or personality to products [29,45]. Research by Schifferstein et al. proposed that the stimulation of multiple senses could create a more pleasing consumer experience [139]. Therefore, combining vision with other senses may be wise, such as tactility and audition in design. For example, Hella Jongerius’ non-temporary ceramics for Royal Tichelaar Makkum offer consumers various sensory experiences (visual and tactile). Non-temporary ceramics employ irregular half-dipped glaze, presenting both glazed and unglazed states in a single ceramic piece. This design not only assigns unique features to ceramics but also shows consumers the differences in the process of making ceramics. In addition, this design also encourages consumers to experience the tactile difference between glazed and unglazed ceramics by touching them to increase their interaction with the ceramics.

There are plenty of typical design cases which adopted the Interaction (5a) design strategy. For example, a seasoning jar with mouse whiskers printed on it displays the interesting movement characteristics of mice when vibrating the body of the jar; a cup designed as a fist can "fist bump" with other people when being used; the blade of scissors is designed to resemble the mouth of a crocodile, and when this pair of scissors is being used, it is like a preying crocodile [105] (pp. 154–156). A reel of thread designed as a pig's nose shape looks like a chubby little pig when it is rolling [140]; a kettle with a smiling face seems to be talking to consumers when it is being used.

Some other interesting design cases integrated the Interaction (5a) with other design strategies. For example, by integrating the Symbolism (4b) and the Interaction (5a) strategies, the Japanese studio Nendo created the Hyouri series of reversible traditional paper Lanterns, which symbolized the traditional culture of Kyoto. Besides, its reversible bamboo frame allows it to be flexibly changed by consumers, which increases the fun of interaction with consumers. Another example is the "Mom 'n Baby" socket designed by Matthieu Manche who is a French designer living in Tokyo, Japan. He integrated the Interaction (5a) and the Narrativity (3b). The shape of the socket is like a baby just coming out from his/her mother's stomach, and its irregular shape is also reminiscent of the scene of cell division and reproduction. In terms of materials, Manche used a prosthetic material that was often used to fill in missing parts of the human body. The Mom 'n Baby socket brings back memories of childhood and mother, and its special material provides consumers with a tactile experience that is different from other similar products.

With the second supplementary strategy (5b) in mind, the designers are expected to improve interaction by promoting consumers to assign their personalities to products [29,45,52,57,110–113]. Scholars found that consumers' emotional attachment to a product will be enhanced when they personalize it [105,141,142]. Consumers are increasingly provided with opportunities to design their own products. For example, Swatch launched the "Swatch X You" service, allowing consumers to design and create their own unique Swatch watches under the inspiration of art and culture [143]. In the DIY process of Swatch watches, Swatch ensures the quality of the finished design and the satisfaction of consumers through limited picture selection, and avoids the negative impact of upward comparison among consumers [105,144]. Secondly, Swatch also provides enough creative space for consumers despite the limited selections. In addition to freely and precisely arranging patterns on watch band and dial, the styles and colors of mechanical parts such as pointers and other components can also be selected by consumers themselves, so that consumers can maintain a sense of design autonomy [145,146]. Similarly, the iPhone 13 launched by Apple has five optional colors, which provides consumers with personalized choices. Furthermore, brands such as Lego, Nike, MUJI, Converse, Oroog, Pandora, Louis Vuitton, etc., offer consumers services that enable them to design their own products.

3.6. Innovation

The "innovation" design strategy [67,74] is formulated to strengthen consumers' attachment to products by creating new using routines, rituals, experiences, and usages of products through design. With the first supplementary strategy (6a) in mind, designers may create new ways of using by modifying some attributes of products, either specifically or symbolically [45,110,114,115]. A typical example reflecting this strategy is the juicy salif lemon squeezer designed by Philippe Starck (as shown in Figure 6). With an elegant and peculiar shape, the lemon squeezer differs from any other similar products in the market in terms of its shape and material. Therefore, its function is completely unrecognizable from its appearance—but consumers are excited, confused, amazed, and full of expectations when they are told that it is a juicer. It goes far beyond what one might expect from a juicer, and makes juicing an everyday activity out of the ordinary. Hence, the rich and special long-term experience transforms the juicer into something more than just a tool with a juicing function. There was even a rumor that Starck said, "my juicer is not meant to squeeze lemons; it is meant to start conversations" [77] (p. 112) [105] (p. 2).

Figure 6. The Juicy Salif Lemon Squeezer (picture by Niklas Morberg).

The Refillable bottles, designed by an Italian designer named Emanuele Pizzolorusso, were launched in ten cities around the world. The bottle was made of PBA-free plastic, and it had the name of each city printed on one side and the address of each city's public water dispenser on the other. Consumers were less likely to buy single-use bottled water since they could look for water sources printed on the bottle to refill their bottles while traveling in one of the ten cities. Pizzolorusso increased the use of Refillable bottles through packaging design, so that Refillable bottles could increase consumers' attachment to the bottle by meeting their demand of looking for public water resources. In addition, Gwyn M.Lewis integrated the Innovation (6a), Enjoyment (1a), and Interaction (5a) design strategies in her design works. She created a fun package for wool yarn named "News of the Wooled Introduction To Knitting". To attract consumers' attention and to make them interested in the weaving process, Lewis designed the packaging of wool yarn in the shape of a sheep. The packaging board neatly coiled the twisted strands of wool yarn into a ball, forming the body of the "sheep" and preventing the wool from being soiled. The sheep's front-back was used to hold the wool in place. As the wool was pulled out and used, the sheep's body gradually became "slimmer". Even if consumers may not use the wool, it still could be viewed as a unique piece of art. As the designer said herself, "Each sheep was developing a personality" [147].

With the second supplementary strategy (6b) in mind, designers are expected to reduce the frequency of product replacement through design by creating more uses for the product without the need for additional components [45,55,78,98,100,116]. Current research shows that the decision to replace a product is a step-by-step process involving a constant assessment process [98]. The factors to be considered include the benefits of obtaining a new product, the cost of replacement, the actual state of the old product, and the time and expense required for replacement. Therefore, it is necessary to create more uses for a product, so that consumers can maintain their expectations for the product during its use and thus maintain their satisfaction with the product during the constant assessment process. There are already many examples of using visual communication design to create more uses for products in the consumer market. For example, the Peppa Pig-themed cookies are very popular among children. When children have finished eating cookies, they can get the Peppa Pig-themed coloring paintings on the back of the package by unpacking the box, so that the box may be kept for use in another way. As a result, it reduces the amount of paper and ink needed to print coloring paintings separately. The Jingle Bank, designed by Hellen Lee, is an unconventional piggy bank designed in the shape of a bell. The piggy bank will jingle if it is shaken and become a fun musical toy when it contains coins [148]. In addition, Nicola Enrico Stäubli designed a series of cardboard furniture called "Foldschool" for children to fold by themselves. Furniture patterns and the folding methods can be downloaded for free online, printed on waste corrugated paper, and folded, cut, and assembled by children on their own [149]. Similar examples include Butter by Nadia's Signature collection and Lucia Bruni's Pure Bottle.

The third supplementary strategy (6c) aims at leaving enough room for innovation during design [29,45,117,118]. Past research indicates that adding open or positive space to the design can improve aesthetic enjoyment [150], and also increase the chances of further design [29] (p. 156). With this supplementary strategy in mind, designers should be aware that the initial design can be simple, imperfect, irregular, and rough, which, in return, forces designers to examine the imperfections of the product and explore the unknown aspects to identify or define new design ideas. For example, the basic type of the Swatch is pattern less, leaving room for creative designs that allow artists to create design works on the dial and watchband freely. It is precisely why the interaction between products and designers allows the Swatch always to maintain its vitality and launch some unique models. As an employee of the Swatch said, Swatch is not only a company that makes watches, but also a company that creates emotions [77] (p. 86). There are many other examples of collaboration between brands and designers, such as the Louis Vuitton's Masters Collection bag, the Harry's Limited edition Harry's Men's Care razor, which is a collaboration between the Harry's and a British designer named Tom Dixon, the Lego's "House of Dots" with French designer Camille Walala, the HONOR's Magic Watch 2 launched with artists and designers, the Art Beyond Borders series launched by LIFEWTR collaborated with three artists, and the Mermaid Collection Cosmetics created by Rodin collaborated with artist Donald Robertson.

4. Conclusions

Six design strategies have been proposed in this paper aiming at helping designers to improve the emotional durability of their visual communication design works, so as to achieve the purpose of sustainable use of products. In the first stage, literature review is carried out to study the theories of sustainable design, emotionally durable design and visual communication design. It could be concluded from past research that consumers would develop emotional attachment to products due to some internal factors, such as the need for self-expression, the desire of in controlling of some special products, the need for pleasure, the need for belonging to a group, the need for self-improvement, and the desire for fresh things. In addition, after classifying and analyzing the design strategies proposed in past research, the authors have found that although each design strategy has clear directivity to the emotional needs of consumers, there are about how to actually satisfy these needs through design. Guided by the reviewing results of the first stage, the authors have analyzed several practical design cases related to emotionally durable product design and emotion-centred visual communication design. The results of the second stage show that emotionally durable product design practices can be driven by continuous emotional responses, while the emotion-centered visual communication design practices are mostly driven by short-term or reflexive emotional responses. With combining the results of the first and second stages, this study has proposed six preliminary design strategies, including Enjoyment, Functionality, Narrativity, Symbolism, Interaction, and Innovation. Preliminary definitions have been given to all the six design strategies. In the third stage of the study, the consumer behavior involved in each design strategy is examined. The results of this part of the study indicate that there is a gap between designers and consumers in the understanding of sustainable products. In some cases, consumers may not always choose the most sustainable product [37]. Designers should have a better and deeper understanding of consumers' behavior patterns and thus can design products that meet consumers' actual needs. In this study, two or three supplementary strategies are added to each design strategy (a total of 14 supplementary strategies) to make each design strategy more implementable. Any primary design strategy can be applied together with any supplementary strategy freely. Designers should evaluate these strategies that are most effective in improving consumers' emotional durability based on product types, the status of the consumers, and the current state of the consumer market. The following conclusions are drawn through the above mentions research works.

At the practical level, the design strategies proposed in this paper can provide effective guidance to designers during the design process. It also shows the critical role of emotionally durable visual communication design in influencing consumers' behavior. When consumers are willing to choose and to hold a specific product for a long time, the replacement rate of this product will decrease significantly, and the service life of this product will be elongated, thus the environmental pollution due to the production and disposal of such products will be greatly reduced. These design strategies are proposed after comprehensive analysis of sustainable design theory, emotionally durable design theory, visual communication design theory, design cases, and consumer behavior. In addition, these strategies also remind designers that the design process of emotionally durable visual communication design should not follow the traditional pattern. Rather, design aesthetics and emotional durability should be integrated and communicated to the client in the process of communication prior to the design of the project concept. This new design mode can not only achieve new breakthroughs and innovations in the design process, but also affect consumers' emotional attachment to products in the process of consumption, and even affect consumers' future purchase decisions. In general, although consumers tend to choose products they trust or favor, they may not choose the most sustainable products. Therefore, the design strategies can also guide designers to transform consumers' visible but hard-to-express needs into readable and easy-to-understand information in the design process. Such information would be conveyed to consumers, so that sustainable products can be more easily accepted by consumers.

At the theoretical level, this study treats sustainability as a design principle and puts forward a new research perspective to visual communication design. It includes a re-evaluation of the values that visual communication design should convey, and a re-classification of the fields that visual communication design involves. The research in this paper reminds scholars of visual communication design to shift their research focuses from practical benefits of products to spiritual benefits of products. In other words, scholars are expected to explore ways to satisfy consumers' deeper and more meaningful spiritual needs. In the early research of sustainable visual communication design, scholars were committed to improving the degradability and aesthetic competitiveness of packaging materials. However, this strategy may cause a lot of waste when it is used improperly. This is because even if many consumers may buy beautiful and durable products, they may still choose to throw them away in the short term, and all these extra costs will cause more serious pollution to the environment. Although assessing the impact of visual communication design cases on sustainability is more difficult than assessing the influence of other types of design cases, the findings of this paper strongly support the argument that visual communication design does not only influence consumers' aesthetics, but also change consumers' behavior toward more sustainable use of products. As Walker said, only by endeavoring to make our material culture more meaningful can we expect to contribute more to a sustainable future [27] (p. 31).

The research works in this paper do have limitations, and these limitations could be addressed through future research.

Firstly, in the second stage of this study, it is difficult to quickly identify emotionally durable design cases. It is due to the fact that the search for emotionally durable design cases requires scholars to recall their own experiences in practical design cases as designers or consumers. Therefore, the process of reflection is very important. This process not only provides consumers with better ways to understand products, but also provide designers with suggestions for further development or improvement in the design process. Critical studies on emotionally durable design cases can be further explored as an independent research proposition.

Secondly, in the third stage of this paper, consumers' behaviors related to design strategies are studied, and consumers' feelings and aspirations are taken as the standards for the formulation of design strategies. In the process of the current research, special attention are paid to the change of the emotional relationship between consumers and different products. However, the research in this paper have only involved the purchasing, using and maintenance of products. In future research, the research scope can be extended to product repairation, service and recycling, aiming at increasing the emotional durability of products from the whole consumption process.

Thirdly, this paper adopts the qualitative research method to establish an emotionally durable visual communication design strategy regarding design theories, design practices, and consumers' emotional experiences. The scope of qualitative research involves the research, use and collection of various research materials, including design case studies, summaries of consumer experiences, observation and analysis on products, etc. With the emergence of different problems in the research process, various new research methods have been adopted as the subcategories of the qualitative research, ensuring that researchers can achieve in-depth understanding, thinking and analysis of the materials in their research works. However, the design strategies delivered from the qualitative research method remains flawed. Due to the low reproducibility of the results obtained in the study, the design strategies obtained are not precise and objective enough. In future research, quantitative research is expected to re-examine the design strategies. For example, a questionnaire survey to investigate consumers' responses is expected to more deeply understand how attached they are to different designed products. In addition, extensive surveys on the market response to emotionally durable products are expected to gain a more objective understanding of the design factors that may extend the service life of a product. Quantitative research on design strategies is an ongoing effort. The outcome of this research can be combined with the current ecological environment development situation and consumer market status, to adjust and improve the existing design strategies, so as to ensure that the design strategy has an effective guiding role in the emotionally durable visual communication design.

Finally, the design strategies proposed in this paper aim at maintaining durable emotional connections between consumers and products through visual communication design. However, the impact of the design practice guided by such design strategies on the ecological environment is difficult to estimate precisely. In future research, a new comprehensive evaluation model can be established to specifically measure the actual positive impact of visual communication design practices on the environment. This study can not only systematize the research of visual communication design for emotional durability, but also convey the concept of sustainability to consumers through specific data and provide support for the dissemination of the concept of sustainability.

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Article

When Reality Kicks In: Exploring the Influence of Local Context on Community-Based Design

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Abstract: Social sustainability is becoming an increasingly important topic in design practice, calling for more contextual perspectives on the process of design for social sustainability. This paper presents a retrospective case study analyzing the design process of a serious game which aimed to empower teenagers to organize events to strengthen community bonds. The community context in which the collaborative project took place underwent significant contextual changes due to the COVID-19 pandemic. Analysis using the Ecologies of Contestation framework shows the influence of multiple contextual levels (Socio-cultural, Power, Constructed, and Values-based) on the design process. Moreover, the paper discusses multiple contextual factors which influenced the design process and presents four suggestions for designers to anticipate and benefit from dynamics in these contextual elements. The suggestions regard (1) integrating the temporal dimension in the collaborative design processes, (2) carefully considering (value) alignment between actors, (3) leveraging values in the collaborative design process, and (4) acknowledging and responding to the multilayered nature of communities throughout the design process. As such, this paper explores the relationships between the community context and the collaborative design process to contribute to more resilient design practices.

Keywords: design process; community-based design; digital civics; context dynamics; co-design; civic communities

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1. Introduction

Social sustainability has become an increasingly important topic in design [1], because it contributes to our basic human needs such as happiness, safety, freedom, dignity, and affection [2]. Social sustainability is one of the three pillars (social, economical, ecological) of sustainable development and is essential to "protect and enhance the natural environment and social equity" (p. 3 [3]). Moreover, social sustainability is a crucial factor in creating more resilient communities [4] and realizing flourishing societies today and in the future [5]. In their pursuit to contribute to social sustainability, design practitioners aim to "advance the human well-being and flourishing of societies now and in the future provides" (p. 2 [1]). As such, design for social sustainability has started to investigate how civic technologies might contribute to long-term and impactful citizen participation, as well as building local communities [6–8]. Technology design can contribute to the development of social sustainability, for example, by supporting social change through empowerment and participation [1]. Moreover, digital technologies are increasingly finding their place in urban communities to (further) empower citizens, for example, by helping them to organize themselves better, pursue shared goals, or deal with pressing local challenges. Innovative approaches such as serious games [9–11], citizen sensing technologies [12,13], local community platforms [14,15], and city-wide interventions [16] are being explored to help communities take charge of their everyday lives and foster social connections among citizens. Many of these projects fall under the banner of *digital civics* [17], which zooms in on the role that digital technologies might play in a move from transactional (top-down) to relational (bottom-up) models of societal organization. All of these developments illustrate how (digital) technologies can contribute to social sustainability by supporting local communities to create positive local and social change [18,19].

Design for social sustainability is, essentially, a contextual and participatory practice [20], requiring the engagement of local communities and a place-based approach to create social connections and locally embedded solutions [21–23]. In order to create local social change and to empower communities through design, design researchers are urged to look beyond the creation of technological interventions towards "successful establishment of its usage in a practice context" (p. 114 [24]). Consequently, design researchers need to navigate and adapt their design process to local community dynamics [22]. Furthermore, local perceptions of technology can influence adoption and participation [25], and local power structures can influence who can participate in the first place [26]. These examples suggests that designing with and for communities to increase social sustainability is a continuous effort of connecting technological interventions with existing practices and local dynamics. As such, the research efforts on (community-based) design begin to outline that the context (i.e., social, cultural, political, economical, physical) plays an influential role in design with and for communities [27]. However, it is still open for debate how and to what extent the local context could influence the design for social sustainability [28]. Through this study, we contribute directly to the call for more contextual perspectives on design for social sustainability [1]. To do so, we analyze the interplay between the community-based design process and its context. We outline multiple contextual factors that might influence design for social sustainability and outline four suggestions to help designers better navigate contextual dynamics to create more resilient design practices and outcomes.

In order to explore the contextual influences on the design project, we review a design for social sustainability project situated in The Hague, the Netherlands. The project was set up to empower local teenagers through technology design to organize events and, as such, strengthen community bonds between the teenagers and their neighborhood. The case was chosen because the project and environment were significantly affected by the COVID-19 pandemic, resulting in profound contextual disruptions which could be studied. The anti-COVID-19 measures resulted in three distinct periods: before, during, and after the first lockdown in the Netherlands. We adopted the Ecologies of Contestation framework [29] as a lens to examine the dynamic community context in the case study [22] from four angles: the Socio-cultural, Power, Constructed, and Value-based Ecologies. Analysis through the Ecologies of Contestations framework helped to reveal the context dynamics that influenced the design process.

This paper is structured as follows: firstly, we introduce the notion of *context*, previous work on design in the community context, as well as the Ecologies of Contestation framework [29]. Next, we present the case and our analysis of it Then, we present the results based on the Ecologies of Contestation framework. These results describe how the contextual changes affected the design process on each of the ecologies. We then zoom out and discuss how the contestations between ecologies influenced the design process. We conclude with four suggestions for designers and a reflection on the use of the Ecologies of Contestation framework. The design suggestions regard the temporal aspect of design processes, (value) alignment between actors, leveraging values in the design process, and accounting for the multilayered nature of communities throughout the design process.

2. Theoretical Background

The case explored in this study is characterized by recent developments in the field of *digital civics*. Digital civics arose as a response to the desire for making the interaction between citizens and municipal actors more relational rather than transactional [17]. Since then, the field of digital civics has developed into a wide plethora of approaches that all aim to deal with wicked or systemic issues through the application of technology for citizens [30]. These issues can concern, for instance, place-based policy-making [31], advocacy and civil rights [15] or using maker-approaches to engage local communities [32]. As such, digital civics projects generally aim to empower citizens and civic communities through technology [30]. The case presented in this paper falls within this interest and is focused on exploring opportunities to (further) empower a community of teenagers and their youth workers to organize community events supported by a digital serious game. Within the analysis, we specifically explored the influence of the community context on the collaborative design process.

2.1. The Community Context

Context has been extensively discussed in various domains. Our research builds on perspectives from within psychology and Human–Computer Interaction domains. Dey and Abowd [33] describe context as any information that helps to characterize the situation of relevant entities (object, people, place) in cases where people and applications interact. This description primarily focuses on understanding the influences of contextual characteristics on human–computer relationships. Such a perspective is also prominent in the work of Sleeswijk Visser et al. [34], who refer to context as "all factors that influence the experience of a product use" (p. 121 [34]). These definitions suggest that interactions and experiences are best understood in the situation in which they arise. Research in community settings mirrors this perspective and focuses on how community behaviors and expressions are best understood when their context is also known and understood [35]. Huntington et al. [35], for example, describe how members of an indigenous community in Alaska regard wildfires as part of the challenges they encounter in their lives, rather than as a central concern; a preposition the respective researchers only could understand after engaging with the community in context. Scholars in the field of community psychology propose an ecological perspective to assess behavior in the situation in which it arises [36]. The ecological perspective proposes that multiple ecological levels (e.g., cultural, social, political) can influence community transactions and behavior. Sawhney and Tran [29] brought the ecological perspective to Participatory Design in their *Ecologies of Contestations framework* to navigate (possible) challenges that may arise from the complex and multifaceted community context, in which contextual components (i.e., values and priorities, local physical environment, trust and power relationships) are intertwined with the collaborative design efforts [22].

In this paper, we apply the Ecologies of Contestation framework to explore the relationships between the community context and the collaborative design process to create more resilient design processes.

2.2. Connecting with the Community Context

In this study, we are specifically concerned with design for social sustainability through empowering local communities to create positive local and social change aided by civic technology [18,19]. However, technology can often not empower a community by itself. In these instances, social sustainability can evolve through community participation in the design process as well as through the outcomes of the collaborative design process [1]. For both effects, community participation is essential and needs to be adequately integrated into local dynamics and infrastructures [22]. In other words, community engagement in the design of civic technologies is often regarded as indispensable for the relevance of the intervention [22,37] and on the basis of in the in situ design processes with and for communities that aim to build community connection [22,38]. The literature outlines various aspects that are influential in engaging communities in design processes. We outline the most relevant aspects for this paper below.

Design researchers can connect to the community context by considering the local motivations and needs as a starting point for the collaborative design process. In fact, aligning ideas and values is necessary to create meaningful collaborations and social connections (e.g., [39–41]). In other words, a sense of mutual understanding and shared rationale for design needs to be developed between community members. A shared rationale could, for example, concern a shared interest, issue, or objective. Various studies describe participatory projects that commenced from local problems (e.g., [16,42]). However, other community-based design efforts point to the need to find a starting point in the communities' interests and goals to leverage the participation [32]. These examples illustrate the importance of grounding the design processes in local values to increase community connection [43,44]. The physical environment also plays an important role in design for social sustainability [21]. Design researchers can connect to the community (context) by embedding local features throughout the design process, for example, by mapping local sights (e.g., [43,45]) or sharing stories connected to the physical environment (e.g., [46,47]). Balestrini et al. [48], for instance, describe how sharing memories about local heritage sights fostered a feeling of pride amongst the participants and subsequently led to more sustained engagement in the participatory process. As such, connection to the local physical environment can be a relevant strategy to leverage community engagement and contribute to more sustainable outcomes [23].

Trust is another critical mechanism to successfully involve and engage with the community to further develop social relationships during the design process. In fact, Corbett and DiSalvo [49,50] have highlighted that trust is a core topic in work on digital civics. Trust is crucial in digital civics projects because a relational model of citizenship means that services and relations will be less well-defined than in transactional ones [49], placing a premium on trust between parties to foster mutually beneficial and effective relationships. Other scholars also point at the importance of building trust in community–researcher collaborations (e.g., [38,43]) and describe how a bottom-up approach and collaboration over extended periods are essential to building trust relationships [51,52]. Therefore, establishing trust with the local community is a way to better connect to local (power) relationships and networks.

In conclusion, the reciprocity between the design process and the community context creates a complex and dynamic environment, where design researchers and communities work together to create technologies that emerge from and simultaneously can be integrated into the local context in order to further empower and build the community [53–55]. Such a grounding in local infrastructures, resources, and other contextual factors, like values and relationships, allows design practitioners to establish more resilient community engagement and design outcomes [56–58].

2.3. Ecologies of Contestation Framework

The Ecologies of Contestation (EoC) framework helps design researchers to reflect on participatory practices in real-world situations on multiple contextual levels [29]. The framework is chosen for this research as it allows to structurally explore contextual levels relevant to the participatory design process. In other words, the framework enables the exploration of relationships between the design process, participating actors (i.e., social, cultural), and their surroundings (i.e., physical, technical). The EoC framework proposes that multiple contextual levels can be distinguished in these real-world situations. As such, the framework supports design researchers in examining the "interrelated layers of social, political and ultimately value-based considerations that emerged in their design practice" (p. 175 [29]). These layers are grouped into four Ecologies of Contestation, briefly outlined below. *Socio-cultural Ecology* looks at the socio-material context of the design efforts and focuses on the political, social, and cultural environment of the design process. How do these aspects influence the process? *The Ecologies of Power* examine the power dynamics at play between the actors. These dynamics can be already established connections and dynamically evolving relationships during the design process. The constructed and designed interventions are the focus of *Constructed Ecologies*, which concentrates on how materials and mediums are used and created in the design process as well as how they influence participation in the design process. Finally, *Value-based Ecologies* consider the way meaning is created throughout the design process. Value-based Ecologies look at the actors' values and how these values influence the design process.

While the ecologies can help to reflect on multiple interrelated layers in participatory design processes, the EoC framework specifically supports reflection on the *contestations* that arise when ecologies are not aligned. Contestations refer to the challenges, disagreements, confrontations, resistance, concerns, and obstacles that can emerge in the participatory processes. In the present work, we adopt this framework to examine how misalignment in a range of contextual influences falling under all four ecologies potentially influenced the community-based design process.

3. Retrospective Case Study Approach

This study aims to explore how the community context influenced the collaborative design process in a design for a social sustainability project to help design researchers better anticipate contextual disruptions and orchestrate more resilient and inclusive community-based design processes.

To contribute to this goal, we present a case study [59]. According to Yin [59], case studies are useful when there is no clear boundary between the phenomenon studied, and the context it unfolds in. As such, the case study approach is relevant in our study on the influence of the context on the design process. The case is selected because of its prominent and significant contextual changes due to an unexpected COVID-19 pandemic, which impacted the community-based design process. The disruptions helped to draw out and explore the contextual factors that influenced the design process. In the design project, the design team worked together with a local youth worker, a community of teenagers, and an industrial partner to co-create and implement a serious game to empower the community to organize community events and as such support community building between the teenagers and neighborhood residents. The case study is delimited by the design process, which stretched across a year (September 2019–September 2020), and covers the periods before, during, and after the first COVID-19 lockdown (March–July 2020) in the Netherlands. The case is analyzed on four contextual levels using a critically reflective approach [60]. In the following sections, we first describe the design process analyzed in this paper, and then we describe the data collection and how we conducted the retrospective analyses.

3.1. Case Description

3.1.1. Setting

The analyzed design project is situated in a community center in the suburbs of The Hague, the Netherlands. The respective neighborhood is generally considered as an underprivileged neighborhood because it faces socio-economic issues, such as poverty, unemployment, and poor housing quality [61]. The community center is managed by a social welfare organization (SWO) and provides legal and social support to residents. The community center is open to everybody from the surrounding neighborhoods and functions as an important local meeting place for both the young and the old.

The SWO employs multiple youth workers who each work with a specific sub-group of local youth. One of these youth workers, Ammar (Ammar is a pseudonym for anonymity purposes), was involved as an actor in the presented design process. His work focuses on supporting teenage boys aged 13–18. The teenagers come to the community center for Ammar's advice, support in personal matters, and to participate in activities. Ammar organized activities to teach the group skills that could contribute to active citizenship (e.g., being proactive, speaking up) and educate them about sensitive topics (e.g., knives, debt). A dedicated room in the community center was available during multiple moments each week for the teenagers to relax and socialize. During these moments, the teenagers could access the community centers facilities, such as couches, the PlayStation, and table tennis.

3.1.2. Project Aim

The project under review aimed to empower a group of teenagers to organize community events. To achieve this, the project intended to create a digital technology complemented by a set of co-creation workshops in collaboration with Ammar and the teenagers. The digital technology had to support the teenagers in organizing local community events, making them more resilient and independent, as well as reducing the youth worker, Ammar's, organizational workload, which in recent years of the community's existence seemed to become an issue.

3.1.3. Digital Technology: UpTrek

The design project involved an industrial partner, a gaming company, to facilitate the development of the digital technology. The industrial company provided UpTrek, a serious game developed to facilitate learning processes and behavioral change. UpTrek had already been used in educational programs to support students in practicing their negotiation skills and in company settings to support the onboarding of new employees. The UpTrek platform consists of modules, such as a negotiation game, dialogue exercise, poll, strategy game, reflection exercise, or quiz, which could be combined to fit the target context (see Figure 1 for images of UpTrek). This flexibility was convenient for the research team and Ammar, allowing them to adjust the game to the research setting.

To apply UpTrek in the case study, the research team combined modules so that UpTrek became a resource to be used by the teenagers while organizing their events. The finished game challenged teenagers to think about what could happen during the organization of their event and develop an alternative plan. It also offered a negotiation game to experiment with using the budget and a step-by-step guide supporting the subsidy application.

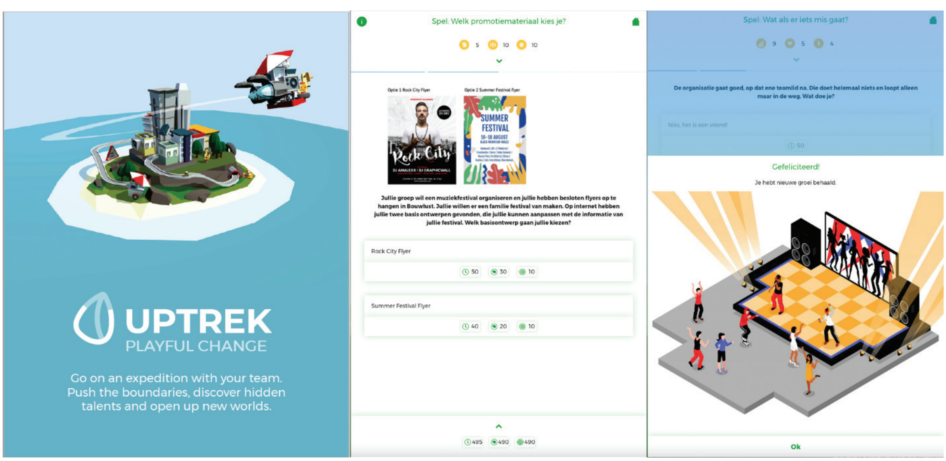

Figure 1. Impression of UpTrek: on the left is shown the island that develops and grows as players progress in the game, the middle and right images provide an example of the strategy game.

3.1.4. Collaboration and Organization

Co-creation workshops [62] were adopted as an approach throughout the design process to engage with and involve participating actors. The collaborative process involved multiple actors: the research team, an industrial partner, and the local community consisting of Ammar (youth worker) and a group of teenagers (see Figure 2 for an overview of when each actor engaged in the design process). The design team consisted of three designers (all authors of this paper) who worked closely with Ammar throughout the design process. Ammar was the prime connection to the community center, the SWO, and the community. Therefore, he was responsible for involving the teenagers and organizing meeting rooms and other facilities in the community center. The research team was responsible for developing the serious game and workshop program based on the input from the other actors. The industrial partner provided technical input and helped to situate the game in the setting. Progress was regularly discussed between Ammar and the research team to assure appropriability for the setting. The teenagers were invited to co-creation workshops to provide input for game development and organize community events.

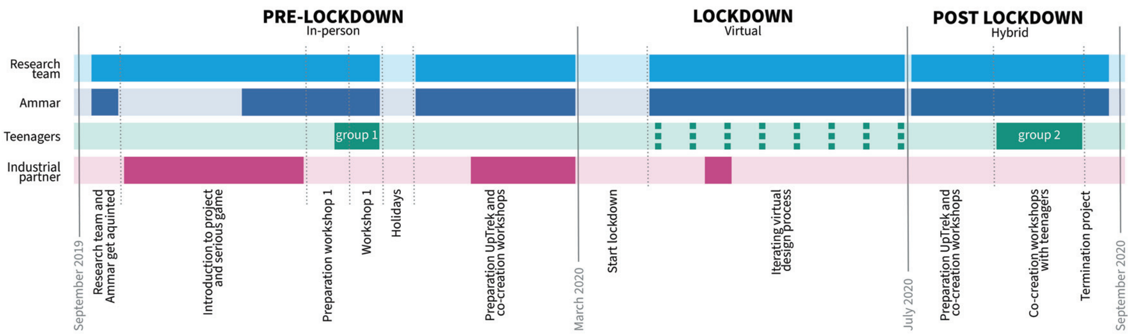

Figure 2. Schematic representation of the involvement of all actors throughout the design process.

3.1.5. Community Involvement

Ammar arranged community involvement by inviting teenagers who had previously expressed interest in organizing events. Eight teenagers (aged 14–18) accepted the invitation. They participated voluntarily and would receive a small reward in the form of a cinema ticket upon completing the project. A cinema ticket was the kind of compensation Ammar used more often when teenagers would do something for the broader neighborhood community. Ammar attempted to engage with the teenagers via WhatsApp during the lockdown period. However, he lost contact with most community members during that time. Therefore, Ammar recruited a second, new group of teenagers upon the re-opening of the community center. He invited the teenagers who returned to the community center to this group. Six community members (aged 13–16) accepted the invitation. They participated voluntarily but were also offered a reward: the teenagers would receive free entrance to one of the summer activities in the community center upon completion of the project.

3.2. Data Collection

The University Ethics Committees approved the design project. All participants and their adult guardians provided informed consent for participation. The design team aimed to create a safe environment for the teenagers to participate and share their ideas throughout the project. One of the designers' priorities was to create a degree of trust amongst the participating teenagers. Ammar advised not to make any audio or video recordings during the first meetings with the community to support this. He explained that recording sessions would potentially influence participation as it could create a setting in which the teenagers would feel like they were checked and expected to give the "right" answer. However, as both groups of teenagers did not participate long enough to establish a trust relationship, no audio or video recordings could be made.

Data were collected in the form of notes (field notes, logbook, meeting minutes), questionnaires, e-mail conversations, and activity outcomes throughout the design process. For example, during each meeting and workshop, the designers took notes and elaborated on these notes afterward with additional information and reflections.

We collected 22 notes, 94 e-mails, two questionnaires, outcomes from three workshops, 18 pictures from the workshops, and session outputs for the analysis.

3.3. Retrospective Analysis

The data were analyzed through the prism of the EoC framework. The analysis process consisted of four steps. First, the data were mapped on a timeline in the three distinct periods by the first two authors to create an overview of the design process and map the data referring to the community context. Researchers used an online white-boarding tool (Miro (See www.miro.com, accessed 3 February 2021)), as social distancing and travel restrictions were still in place.

Next, the timeline was validated in a virtual meeting with Ammar. The semi-structured interview aimed to verify and elaborate the mapped design process and ask additional questions related to the four ecologies. The researchers also used this meeting to validate and extend their insights into the teenagers' attitudes with Ammar. To illustrate, Ammar provided more insight into how he had experienced the lockdown and how the lockdown had impacted the teenagers. He explained, for example, how the teenagers felt scared at the start of the lockdown and how this turned into frustration, incomprehension, and anger towards the end of the lockdown period. During this meeting, one of the researchers mainly focused on asking prepared questions, and one took notes directly on the online whiteboard. The notes functioned as input for the conversation, and Ammar could elaborate and respond to them. In later parts of the paper, we will refer to this meeting as the *evaluation* with Ammar.

As a third step, the researchers individually examined the mapping and prepared clusters on similar themes. Then, they met and jointly clustered the data of each period in the four ecologies. For example, data related to Ammar's initial priorities would be placed in the first block (pre-lockdown) in the Value-based Ecologies. This step resulted in a matrix of three by four squares filled with data (see Figure 3 for a schematic representation of main insights).

	PRE-LOCKDOWN Community center open	**LOCKDOWN** Community center closed	**POST-LOCKDOWN** Community center open (access restricted)
Socio-material Ecology	The community center is a local meeting place for the community and has a formal, supportive function and an informal, social function. Relating the design process to the community center's activities helped lower participation barriers and developed connections with teenagers.	The lockdown disturbed the social and cultural context; most people had to stay home and could not meet in person. the community center had to close The design team lost its links to the context and the community.	Some COVID-19 related measures were still in place. The community center seemed to have lost its function of uniting people. The design team and Ammar could not connect with the community as intended in the hybrid workshops.
Ecologies of Power	Ammar is interested in UpTrek; the design team is interested in community participation. A balanced power relationship between Ammar and the design team arises, resulting in a fruitful collaboration.	The teenagers do not engage in the virtual design process. Power relations are imbalanced due to designers' and Ammar's dependence on the teenagers' engagement in the community activities and design process.	Changed relationship between Ammar and teenagers, less engagement from the side of the teenagers; teenagers' engagement quickly declined throughout the workshop series. Ammar and the design team could not refind their collaborative dynamic.
Constructed Ecologies	The design team and Ammar gained more profound insights into the context. They adapted the role of UpTrek in the process to fit contextual insights and characteristics.	The community center did not have any virtual presence or infrastructures. Ammar and the design team had to develop a digital social infrastructure from scratch, as there was no locally existing practice they could connect to.	Travel restrictions prohibited the designers from being present in person at the co-creation workshops. The hybrid workshop format might not have facilitated the degree of in-person contact needed for this community at this point.
Value-based Ecologies	All actors had clear priorities, goals, beliefs, focus, intentions, and attitudes. The development of UpTrek sparked a conversation about priorities, goals, focus, and intentions. The beliefs and focus of the designers shifted.	Due to the lockdown measures, shifts occur in priorities, goals, focus, and intentions among actors. It was hard to get a grip on the teenagers' perspectives and evolve the design process accordingly.	Ammar and the design team expect priorities, goals, beliefs, focus, intentions, and attitudes to resemble a pre-lockdown situation. Disengagement of the teenagers shows that these expectations might have been wrong and that priorities, goals, beliefs, focus, intentions, and attitudes evolve.

Figure 3. Schematic representation of the main dynamics in each ecology.

Finally, the third researcher was involved in joint reflection on the complete grid. This reflection helped further understand the relations between the ecologies, the influence of the author's values on the process and summarize the insights. The third researcher was especially suited to join this part, as he had helped set up the project and then left, so he knew the project background but was also able to provide a fresh perspective. The discussion results were then written up and can be found in the following sections.

4. Results

The results section presents our exploration into the effects of the context dynamics on the collaborative design process through the lens of the EoC framework. Each section describes a respective level of the ecology and is structured according to the three distinct periods of the case study: pre-lockdown, during the lockdown, post-lockdown. The results are also summarized in Figure 3.

4.1. Socio-Cultural Ecology

Socio-cultural Ecology focuses on the political, social, and cultural environment of the design project. In this study, the Socio-cultural Ecology mainly concerns the interactions between the design process and the community center and its facilities, the social community infrastructures, and the impact of the COVID-19 policies.

Before the imposed lockdown, the community center was a popular place for the teenagers to meet. According to Ammar, the community center was a place to build friendships, share personal stories, learn new skills, find help, and have fun with peers. The social role is reflected in Ammar's remark during the evaluation meeting: *"the boys often have seen each other in other places, but they build friendships through the activities in the community center"*. The first co-creation session with the teenagers further illustrates the social function of the community center. When the teenagers brainstormed about the ideal community center, they listed a big part of their already participating activities (e.g., table tennis, PlayStation, indoor soccer), signaling their appreciation for these activities. One group even wrote down: *"There are few places where you can go when the community center is closed"*, signaling how the community center was an important place to meet for the teenagers. One of the groups even worked on creating a plan for extending the opening hours of the community center during the co-creation workshop. These examples illustrate the social role the community center and SWO played in the lives of the teenagers. Many teenagers also came to the community center to access personal support, something they could not always find at home. As such, Ammar was in daily contact with many teenagers before the lockdown: *"I am in daily contact with some of them, they see me as an older brother or father"*. Here, Ammar relied primarily on in-person contact. He developed a trusting relationship with the teenagers through his community center program based on their input and informal contact as he explained: *"I look for them when they meet each other outdoors in the neighborhood and chat with them. This helps me to connect with them and provides input for the program"*. As such, the community center seemed to have a formal function (personal support, access to facilities) and an informal, social one (meeting peers, having fun, and a place to go) for the community. These functions made the community center an excellent gateway for researchers to engage with the community. Positioning the project as part of the community center's program helped the design team embed the project in the community infrastructures and, as such, lower participation barriers.

Then, the Dutch government imposed a nationwide lockdown to respond to the COVID-19 pandemic. For many people, the regulations greatly influenced their daily lives; children had to stay home, everybody needed to work from home, it was impossible to practice sports together or meet friends and family, to name a few examples. The sentiment of this period is illustrated by one of Ammar's e-mails: *"It seems like I am playing a part in a bad B-movie"*. The lockdown was a big hit for the community because their lives changed drastically. Most teenagers lost their jobs, social contacts, and leisure activities. The lockdown also required the community center to close, leaving the teenagers without physical access to its facilities and support, as Ammar wrote in an e-mail: *"A big part of the activities is canceled because physical contact is a key requirement"*. Losing the community center as a place for in-person meetings and community building required substantial changes in the design process. Virtual and hybrid forms of meetings seemed logical and helped the designers and Ammar stay in touch. Due to travel restrictions and the closed community center, the designers had to rely on Ammar to connect with the community. However, the loss of in-person contact also made it challenging for Ammar to maintain his relationships with the teenagers. The loss of the facilities of the community center and the significant changes in the actors' daily lives changed the design process from a locally embedded process to a process detached from the physical and, to a large extent, social context; the gateway to the community was lost. In conclusion, the political context (COVID-19 regulations) strongly disturbed the community's social context (i.e., access to a meeting place that is built on trust with the community worker) and cultural context (i.e., preference for face-to-face interaction, instead of digital). Consequently, it weakened the design team's links to the community.

After almost four months of lockdown, the COVID-19 policy relaxed, and the community center could open its doors again. Meanwhile, some restrictions were still imposed, which limited the number of people allowed in the community center and required social distancing measures. These rules challenged opportunities to organize activities due to maximum capacity and social distancing. During the evaluation meeting, Ammar explained how the community center had become less of a central meeting point due to such COVID-19 policies: there was much paperwork connected to organizing something, and only a limited number of people (25–30) could join activities. Altogether, the function of the community center to unite people seemed to be challenged by the previous four months of lockdown. Only a few teenagers returned upon opening the community center. Ammar found that even the extended contact with boys who used to come to the community center for over ten years was (partly) lost. As he described during the evaluation: *"Teenagers that had visited the community center for over ten years did not return after the lockdown. Only a minimal amount of teenagers came back."* He expected the community center to be less of a central place due to the barriers imposed by the measures. Due to the past contextual changes, the community center could no longer take back its former role in the design process. It became less of a gateway to the community, making it harder for Ammar and the design team to (re)connect with the teenagers as intended.

These changes in the Socio-cultural Ecology indicate that both the physical meeting point and in-person contact played a role in preserving the community in its original form. The community center was shown to be an essential place for formal and informal, in-person gatherings, reflecting the community's social culture and infrastructures. Access to this meeting point was disturbed due to changes in the political environment (lockdown). The ways of establishing and maintaining connections that worked before the lockdown were suddenly not applicable anymore. Online substitutes, such as WhatsApp and video-conferencing, could not be turned into a social infrastructure able to successfully combat the lack of face-to-face interactions in the community center on such short notice. After the lockdown, the social community infrastructures seemed to have changed, leaving the designers with weakened connections to the community.

4.2. Ecologies of Power

The Ecologies of Power consider the power relations within the case study, which were first primarily found between Ammar and the designers, and later between Ammar, the designers, and the teenagers.

At the start of the project, the power relationship could be primarily observed between the design team and Ammar. On the one hand, Ammar was interested in the UpTrek technology that the design team offered. On the other hand, the design team's intentions of an inclusive and participatory design process required the participation of the target group, the community of teenagers, to which Ammar had access. As Ammar and the design team needed each other to reach their goals, the power balanced out and encouraged both parties to align interests and values, in other words, to collaborate. Indeed, we observed that the balanced power resulted in a fruitful collaboration where both Ammar and the design team knew what the other was looking for and could provide in the design process. At this point, the teenager's relationships with Ammar were healthy and active, and thus their role in power relationship was rather considered insignificant.

Throughout the lockdown period, Ammar lost contact with the community of teenagers (as described in Socio-cultural Ecology), which he had to offer to the design team. This change would suggest, thus, that the power shifted towards the design team, as they still had UpTrek technology to offer, and Ammar was still interested in it. However, that seemed not to be the case. First and foremost, Ammar's main focus was still, rightfully, to support the teenagers, and the design process became less of a priority to him. As he expressed in the evaluation meeting:*"My focus changed, as I did not know what was going on in their home situation, because I did not speak to them anymore"*. In this case, one would think that the power shifted to Ammar's side. However, the power dynamics in the relationship between Ammar and the design team were imbalanced by their dependence on teenagers' engagement in community activities and the design process. These difficulties made collaboration harder and caused the design process to slow down, which is reflected in the speed of the e-mail conversation and the difficulties in scheduling meetings.

When the community center re-opened, Ammar and the design team tried to re-establish their fruitful collaborative atmosphere by resuming their pre-lockdown plans. Ammar recruited a new group of teenagers from the community to resume the activities where they had stopped before the lockdown. Unfortunately, the initial enthusiasm of the teenagers did not last: *"During the first co-creation workshop it seemed as if some of the boys were less motivated and were only there for the reward activity they could get"* (Ammar, in his logbook). The gradually decreasing involvement of the teenagers' community and the inability to find again the same collaborative dynamic as before the lockdown eventually led to the termination of the project.

The fluctuations in the power balance suggest that the community had implicit power over the relationship between Ammar and the design team, which was neither explicitly addressed by designers nor by Ammar. The Ecologies of Power suggest that all actors were related to each other and influenced the power balance during the design process. The designers depended on Ammar and the community to run their design process; Ammar cared for the community and depended on the design team for innovation. Lastly, the teenagers relied on Ammar for help and access to the community center and its activities, of which participation in the design process was one. The designers and Ammar potentially underestimated the power of the teenagers over the process. This underestimation might have contributed to the power imbalances and decreased collaboration during the design process.

4.3. Constructed Ecologies

Constructed Ecologies focus on how the materials and mediums constrain or support interaction and co-creation with the community throughout the design process. In this case, the Constructed Ecologies mainly concern digital technologies that facilitate online meetings and UpTrek.

Before the lockdown, the design team adapted UpTrek to fit the project aims. However, the construct of UpTrek appeared to be less suitable for the project context than the design team had imagined because of the games' clear competitive elements. Ammar and the design team expected that the focus on competition might be counterproductive in this sensitive context. As explained in the designers' notes:

> "We concluded that making a competition out of organizing events is probably not the right approach, for a couple of reasons: (1) it is tough to compare different community events, as they can differ in many ways [. . .] (2) when using UpTrek to score points, you are having a competition on how well you can read and perform in mini-games, instead of on the real event and organizational skills and (3) it is nice to score many points, but being last in the ranking has probably way

> more negative impact than the positive effect of scoring points. As such, we think it would be better not to have a competition and for example have a couple of prizes in the end that are awarded by us (e.g., nicest idea, best teamwork) so all groups can win and have a nice moment to close the project." (Designers' notes)

In other words, the competitive elements were expected to draw away the attention from organizing the event towards performance in mini-games. Therefore, Ammar and the design team decided to decrease the competitive elements in the game and give UpTrek more of a supportive role (providing relevant information) rather than a leading role with a focus on competition. The context in which UpTrek would be applied highly influenced its final shape. In other words, Ammar and the design team discovered that their initial assumptions about UpTrek's potential were presumably wrong when they had explored the context of use more in-depth. They understood that competition could potentially negatively influence the social ties that kept the community together.

Then, the lockdown implied a switch to digital tools for social gatherings, blocking the intended project set-up and intended use of UpTrek. Ammar and the design team proceeded with online meetings to cope with the changing environment. As the community center had not yet established a practice of meeting each other digitally, there was no existing digital infrastructure to which to connect the design process, nor an online format to apply. The design team and Ammar had to reconsider their approach to engaging the teenagers virtually. To do so, they explored the potential of a digital community center, joining another initiative focusing on making information accessible through QR codes and organizing online co-creation workshops. However, these attempts did not leverage community engagement. In conclusion, the lockdown changed how people were living drastically. The design team and Ammar struggled to adapt to these new contextual dynamics without direct community infrastructures to which to connect.

Ammar was motivated to reconnect with the teenagers as soon as possible when the community center opened again: *"If it were up to me, we would meet on short notice"*. The initial project setup was reconsidered and used with some adjustments to adhere to COVID-19 related measures. The design team could, for example, not visit the community center due to travel restrictions. Ammar and the design team organized the co-creation workshops in a hybrid format: the design team joined via a videoconferencing platform, and Ammar and teenagers were present in the community center. The hybrid format limited the participation of the designers due to the limited audibility and visibility of participants. For example, the researchers could not see and hear all teenagers. The limited audibility and the hybrid format also created an uncomfortable situation in which the teenagers, for example, needed to walk up to the computer to say something to the design team. Furthermore, by being projected on a giant screen, the researchers stood above the others, limiting the inclusive atmosphere that the design team tried to create. These obstacles made it difficult to follow discussions and participate in the workshop. The challenges are reflected in the notes of the design team, who noted down questions such as *"are these initiatives what the teenagers really want to do?"*. In in-person settings, the designers would have addressed these topics with the teenagers. It seemed like in-person meetings were essential to establish a connection with the teenagers in this post-lockdown period.

The experiences in the Constructed Ecology illustrate that the construct (UpTrek) and mediums (virtual and hybrid workshop setup) in this design project were connected to the local context. The role of UpTrek needed to change drastically to fit the sensitive context and project goals. The workshop series that was applicable in a pre-lockdown context did not remain so during and post lockdown. The online and hybrid design settings suggest that these formats did not support the same interpersonal qualities as in-person meetings. One cannot directly translate offline efforts into online alternatives. The move to a virtual and a hybrid format decreased the possibilities for the design team to build relationships with the teenagers. The virtual and hybrid formats hindered such development due to the unfamiliarity of these tools and their primary focus to support meeting efficiency rather than informal bonding and one-on-one interactions. As such, the Constructed Ecologies suggest that specific in-person components might have been essential to this community-based co-creation process, where the community was vulnerable due to the COVID-19 measures. In this project, focusing on developing (stronger) community ties was especially relevant, but it was probably best achieved when there were opportunities to meet in person. As Ammar put it during the reflection meeting: *"the implementation of online processes needs the be supported by in-person contact"*.

4.4. Value-Based Ecologies

Value-based Ecologies look at how value and meaning were created throughout the design process and consider the values that played a role in the case study. Values were not explicitly addressed during the design process. Therefore, we based this section on our interpretations of the data and Ammar's insights into the teenagers and reflection on our experiences. We interpreted expressions of priorities, goals, beliefs, intentions, focus, and attitudes that potentially motivated or inhibited actions in context as *values*.

Before the lockdown, the development of UpTrek triggered a conversation about project goals and intentions among the design team, Ammar, and the industrial partner. Decisions that needed to be taken about specific aspects of UpTrek elicited actors' opinions and beliefs regarding its development and implementation in context. These discussions allowed Ammar, the design team, and the industrial partner to align their values better. For example, Ammar explained how he valued involvement of the teenagers in the design process, to create a meaningful game for them, as reflected in the meeting notes: *"Ammar explained how he would like to incorporate a part in which we talk with the teenagers and discuss how this is important for them; how it is meaningful"*. Throughout this co-creation process, the attitudes of the design team and their focus in the process shifted. Data from the start of the design process show a focus on exploring the potential of technological intervention (UpTrek). For example, the initial project plan describes the aim of the project to be: *"Designing and developing a playful social gamified course in UpTrek to stimulate citizen participation and empower different communities in specific neighborhoods in The Hague*". Notes reflect that discussions among the researchers mainly concerned the functionality of UpTrek and how it could support the teenagers to organize events. The shifting role of UpTrek (from guiding the teenagers to supporting through information) was bound to the insights of the design team that further empowering the teenagers also required a process and support from the other actors, next to the technological support UpTrek. As such, the priorities and focus of the research team evolved based on a more thorough understanding of the context.

The pandemic compelled all actors to reconsider their priorities to deal with the changes in their daily lives. As Ammar described during the evaluation, *"Reality kicked in for the teenagers due to the forced home-stay"*. While Ammar explained during the evaluation that the community center could cater to teenagers' focus on their friendship, having fun together, and learning new skills, this changed during the lockdown. At that point, other things became a priority for the teenagers, such as taking care of family and restructuring their lives to comply with the lockdown rules: *"Their parents might have forbidden them to go out, some of them were also scared themselves"*. During the lockdown, Ammar became concerned about the teenagers. As he puts it: *"What is happening in their homes? How can I get in contact with them? I do not speak with them anymore; how would they be doing?"*. Consequently, his focus was primarily on taking care of the immediate welfare of the teenagers (rather than educating them). The apparent shuffle of teenagers' priorities and interests made it harder to connect to and involve them in the virtual design process. Consequently, the design team and Ammar had to rely mainly on the experience and insights of Ammar to proceed with the design process in a virtual fashion. The design team wanted to help Ammar in his attempts and left their focus on empowerment aided by serious games and prioritized aligning with Ammar's interests, as reflected in their attempts to find other fitting possibilities to engage the teenagers. However, engaging the teenagers in any online activities failed, hinting at the inability to rightfully cater to their needs and priorities or that this was not the right time for these kinds of initiatives.

Ammar explained the attitude of the teenagers: *"Why would you even put energy in a project? Everything changes all the time. We will see what happens"*. In other words, the primary goals, priorities, and other values seemed to be connected to the contextual situation. The shifts in priorities, goals, and intentions seemed to have impacted actors' engagement and participation in the design process. Ideally, design processes would evolve along with these changes; however, this would have potentially meant a complete shift in the design project.

After the lockdown, the design team and Ammar expected everything to go back to the way it was before the lockdown and anticipated that the priorities and goals of the teenagers would resemble the situation before the pandemic. However, while the group of teenagers that participated before the lockdown was very enthusiastic about the project, part of the second group disengaged during the process. As Ammar described during the preparations of the second co-creation workshop after the lockdown: *"The teenagers are very unpredictable, one moment they are involved and another they are not, one week everything is nice, and the next it is not"*. After the lockdown, the values and priorities of the design team and Ammar evolved again and resembled the situation before the lockdown (empowering the teenagers to organize events), as they expected the context to return to its original form. However, changes in engagement of the teenagers suggest that this shift and consequent setup of the design process might not have been in line with their interests and priorities.

The experiences in Value-based Ecologies indicate that priorities, goals, beliefs, intentions, and attitudes can evolve throughout the design process, especially when significant transitions are happening in the context (in this case, due to the pandemic). Co-creation supported the emergence and alignment of priorities, intentions, and goals among actors throughout the design process. When Ammar and the design team lost touch with the community, they also lost sense of what moved, motivated, or interested them. As such, these examples seem to suggest that designers must carefully consider 'meanings' or values in the context to ensure that their process makes sense. Designers would benefit from addressing values and meanings explicitly in the design process, which was not done here but was observed.

5. Discussion

This paper explores how severe fluctuations in the community context of a design for social sustainability project affected the collaborative design process. The relationships between community context and the collaborative design process were explored using the EoC framework (the Socio-cultural, Power, Constructed, and Value-based Ecologies). This section presents multiple insights that can help design researchers anticipate and react to dynamics in a community context in order to create more resilient design projects focused on social sustainability. First, we discuss the results in light of co-design and Participatory Design literature. Next, we zoom out and introduce four suggestions for future design for social sustainability efforts in the community context. We conclude the discussion with limitations and recommendations for future research.

5.1. General Insights

The perspective of the Socio-cultural Ecology explored how the social (community interactions), cultural (e.g., community infrastructures, habits), and political (COVID-19 measures) context changed due to the imposed lockdown. Most people adopted digital technologies to collaborate, communicate, connect, and socialize during the lockdown period. Additionally, Ammar and the research team attempted to substitute the social infrastructures facilitated by the community center with online alternatives. However, as our results indicate, it was challenging to translate community infrastructures, practices, and routines typical to the physical setting into a virtual variant. We speculate that this is caused by the strong encapsulation of social infrastructures into the physical context [63,64] in this case; in other words, community bonds to the physical location. As such, we suggest for designers to carefully examine the infrastructures at play in the community and find ways to extend and complement these structures rather than to replace them. Our results are in line with the literature suggesting that the developments of alternative or new infrastructures, such as digital interaction spaces, should be developed and implemented gradually and carefully consider the emerging priorities and wishes in the community in question [22,53,57]. Explorations from the perspective of Constructed Ecologies further strengthen these insights by suggesting that the lockdown and post-lockdown situations required certain degrees of interpersonal contact (informal talk, overseeing and participating in the process) between the design team and the community. While developing a certain degree of trust and connection between design researchers and participants is essential in the collaborative design processes [65], the design designers felt limited by the opportunities to build this trust in online or hybrid workshop settings. In conclusion, this community seemed tied to a specific social context, in which in-person interactions (primarily related to the community center) helped sustain the community.

Through the Ecologies of Power lens, we explored how the pandemic influenced what the actors could contribute to the design process and how these shifts consequently altered the power balance. Our case study suggests that the power relations were situational (dependent on contextual factors, such as roles, personal stakes, and priorities) rather than specific to formal power relations, and shifted with they changing socio-cultural context. In our case study, all actors played an essential role in realizing the project goals as of what they had to offer: The designers offered the technology, Ammar—his experience and contacts to the community, and the teenagers—their participation. Each actor held a certain degree of power over the others. The teenagers also, although seemingly implicitly, held some power over the other actors; all actors preferred the teenagers to be part of the design process because the project intended to help them organize events. Such dynamics in the power relations can be found more widely in participatory processes, as these processes generally aim to ensure that all actors have a stake in the outcome as well as equal opportunities to influence the corresponding design process [66]. The results also show how attending to the community became increasingly important during and after the lockdown, as was Ammar's role as an intermediary [67] between community, context, and designers. We suggest to acknowledge this importance of community development throughout the collaborative design process. Continuous alignment of interests and goals of participating actors seems critical to maintaining productive power balances throughout the collaborative design process [68], but might need to be complemented by community-building activities. The significance of alignment also came to the fore in the Value-based Ecologies. The explorations in Value-based Ecology showed that the actors' priorities and agendas changed with on- and offset of the lockdown measures. Co-creation helped to capture actors' preferences and supported the alignment. Other scholars also suggest this positive effect of co-creation on inducing alignment (e.g., [39,44]).

5.2. Insights on the Interaction between Contextual Elements

The use of the EoC framework goes beyond dissecting the context into various ecologies. In particular, the EoC framework poses contestations to emerge when the ecologies do not align [29]. For example, the inability to reflect stakeholders' values (Value-based Ecologies) on the technologies (Constructed Ecologies) can cause conflicts during the implementation of the intervention. The subsequent paragraphs discuss the most significant moments when ecologies did (not) align. These moments are specific to the case study context. Such locality and specificity of the context in the design process are often seen as a research limitation because they hinder the extent to which findings can be generalized [69–71]. However, we do not intend to make our insights generally applicable, but rather attempt to better understand the situatedness of the community-based participatory design processes. To achieve this, we will now present a set of potentially transferable insights about the structure and relationships between various contextual elements and the collaborative design process.

5.2.1. Time as a Lost Dimension

The case study presents notable contextual changes and contestations in all ecologies. These changes resulted, for example, from shifting perspectives among actors towards the design process (e.g., changing interests, priorities, agendas) and adoption of virtual and hybrid forms of running the design process. These shifts draw attention to the temporal dimension of design processes. While Ammar and the design team expected life to go back to the way it was before the lockdown at the end of the project, the dynamics within the design process had changed. These changes again show that the context in which the design process takes place is in constant (subtle) motion. As its context evolves and changes over time, the design process should evolve along, recognizing that most elements in the process are not static. Other scholars also show the need for an evolving and adaptive design process [62,72,73] in which all discuss how design ideas, problems, and solutions evolve as the design process unfolds.

Take-away. We should consider time as a contextual element continuously influencing the design process and therefore integrate the temporal dimension into our current design processes. The design process must allow for reflection and awareness of this temporal element, empowering participants to reflect and act on past, present, and future dynamics in the context. This could for example be achieved by keeping a diary and/or documenting the design process [74,75] and regularly collaboratively evaluating these entries.

5.2.2. Continuous (Values) Alignment

Contestations arose when the Socio-cultural Ecology (preference for in-person contact), Constructed Ecologies (virtual and hybrid interaction), and the Value-based Ecologies (furthering the design project, non-project related priorities) did not align anymore due to the COVID-19 measures. These contestations resulted in difficulties in both the Ecologies of Power and the Values-based Ecologies. The results on these ecologies suggest the importance of continuous alignment of actors' perspectives towards the design process (e.g., priorities, goals, interests, beliefs, agendas) to create a productive power balance (Ecologies of Power) as well as a meaningful design process (Values-based Ecologies). Such a need for alignment echoes work by Jafari et al. [76], who posit that it is impossible to "just" identify shared values at the start of a design process and apply them.

Take-away. Alignment of actors' perspectives within the design process should be a continuous process. As such, we observe the importance of fostering a "dynamic and dialogic process of cultivating the emergence of values [44]" to create a shared frame of reference and continuously review this frame in light of its relevance in context.

The results also show how co-creation of UpTrek and conversations about the importance of the community center (Constructed Ecologies, Socio-cultural Ecologies)-fostered exploration and alignment of actors' goals, intentions, and priorities (Value-based Ecologies) [77,78]. Both UpTrek and the community center were contextual elements with different meanings to the various actors. For example, while the research team regarded UpTrek as a potential tool to facilitate community empowerment, Ammar saw opportunities to boost innovation and efficiency in his work as a youth worker and new ways to support the community. While the community center seemed a gateway to the community for the research team, Ammar saw it much more as a part of the community that should be managed carefully. The community, in turn, experienced the community center as their own, a place where they could meet and relax. In this way, UpTrek and the community center helped the actors get to know each other and their perspectives. They seemed to function as boundary objects [79,80] and allowed stakeholders to share individual perspectives to foster further alignment, a process essential to participatory processes [16,65].

Take-away. In conclusion, the results suggest that certain contextual elements, such as UpTrek and the community center in our case, could support (values) alignment. These elements helped explore each other's perspectives, intentions, and goals. Identification of such elements could aid designers to connect more easily to the context and actors and help them align perspectives throughout the design process. Sharing stories, memories, and narratives regarding the local environment seems to be a valuable method to identify such elements, as well as to uncover (shared) values [43] and create mutual appreciation and pride [48].

5.2.3. Community as a Multilayered Construct

The community (Socio-cultural Ecology) seems dynamic and transforming throughout the design process in the case study. When the lockdown commenced and the community center closed, the teenagers needed to find other ways to stay in contact. The community center was influential in bringing the community together and facilitated continuous community-building activities. As such, it seems that the community center in our case contributed significantly to the identity of the community of teenagers [81]. For example, the teenagers referred to the community center as "their" place, and Ammar called the community "his group". When the community center became inaccessible, the contact between the community and Ammar decreased. The relationship between the community (Socio-cultural Ecology) and community center (Constructed Ecologies) suggests that the community might not be only a socio-cultural construct, but a multilayered construct [82,83], in this case, tied to a physical location.

Take-away. The textcolorredcommunity is a multilayered social construct that changes and evolves. These changes should be carefully considered throughout the design process in order to engage the community meaningfully [42]. The community cannot be studied in isolation. Becoming aware of community context, e.g., contextual elements, such as meaningful objects or places, could help to better understand and connect to the community, as these elements seem to play a role in building community and developing a shared community identity [84]. Practitioners could benefit from identifying relevant contextual elements to embed in the design process to foster community engagement [46,52,85].

5.3. Applying the Ecologies of Contestation Framework

This study is one of the first to adopt the EoC framework as a prism to explore the influence of context fluctuations on the collaborative design process. As a result in this paper, we are able to reflect on the fit of the EoC framework to explore the complex multi-layered contextual influences on design processes targeting social sustainability. The framework assisted the authors in systematically examining the design process on multiple contextual levels (Socio-cultural, Power, Constructed, Values-based) and exploring the relationships, challenges, and opportunities that arose in the design process when the ecologies did or did not align. However, the focal point of the EoC framework in our study was to aid design researchers in anticipating (potential) contestations in the design process. This focus on the obstacles, challenges and other difficulties drew our attention away from the successes and positive experiences during the design process. Future adopters of the framework should be mindful of the focus on contestations the EoC framework brings when applied in the analysis.

Furthermore, while the ecologies provided a valuable tool for analysis, the authors suggest extending the Ecologies of Power when using the EoC on similar cases. While the Ecologies of Power were useful to shed light on the relationships between the various actors, also other relational dynamics seemed to be worthwhile to examine. Trust relationships were, for example, influential in the case study to gain insights into the communities' intentions, priorities, and perspectives. The need for trust became apparent during the first co-creation workshop, where the teenagers tended to give socially acceptable answers instead of expressing their true feelings and wishes. The need for trust has been shown in similar contexts by [65,86,87]. Furthermore, trust in the authorities might have influenced the community's participation. As Ammar explained, the teenagers were unsure if their lives would be the same each day due to the continuously changing COVID-19 measures. This uncertainty resulted in changing interests and frustration, which seemed to have led to rebellious behavior, vandalism, and meetings in violation of COVID-19 restrictions. When we look at these findings in light of Corbett and DiSalvo's work on trust in digital civics [49,50], this is a good example of a failure of the authorities to manage expectations of the community. As such, trust was an influential topic in the design process, illustrating how other relationships beyond power might need to be considered in the Ecologies of Power.

In conclusion, our study illustrates the practical applicability and the potential of the EoC framework to be employed as a lens to examine the interrelations between the community context and the collaborative design process. Researchers should be mindful of the framework's focus on contestations and the possibility to broaden the Ecologies of Power.

5.4. Limitations and Future Work

The design project analyzed in this study focused on designing tools and events for a community to empower them to organize community events. The project's focus was on running the project and collaborative design process rather than understanding the process dynamics. Furthermore, the study's retrospective nature depended on already collected data. Both dynamics have influenced the type and amount of data available for the case study. These limitations were overcome by reviewing, checking, and extending the findings with Ammar and by positioning the study as an exploratory study. Furthermore, two of the authors were involved throughout the design process, making it easier to interpret and consolidate data.

Another limitation that might be found in our work is the fact that values were not explicitly addressed in the design process. Therefore, we specified what we interpreted as values and evaluated these impressions with Ammar. While values were not explicitly addressed in the design process, we observed the importance of attending to values throughout the design process. Therefore, we want to call for a more specific focus on supporting community characteristics such as shared and individual values, attitudes, and goals to be discussed and aligned throughout the community-based design process. Ideally, this would cover empirical research and the development of tools to support articulation and alignment of shared values.

Lastly, we recognize that the abrupt contextual changes from the lockdown measures might not represent a "regular" community process. As literature shows, community building takes time [22,88,89]. Due to the contextual changes and the accompanying shifts in perspectives and priorities, such a community-building process became difficult to realize for the designers. Authors are in doubt as to whether the research team could have done much to counter the experiences of the teenagers and *suspend doubt* [49] in authorities as a consequence of the changing lockdown measures. Many of the factors influencing the lives of the youth after the lockdown were beyond the control of the research team. Thus, while the contextual changes might not have represented a "regular" community process, these changes did allow us to draw out and investigate the relationship between the community context and the collaborative design process. Drawing out such relationships was expected to be more difficult when contextual changes would have been more subtle.

This retrospective study has provided more insights into the interrelations between the community context and the collaborative design process. While this study provides multiple applicable insights and design suggestions, we acknowledge that a more structural approach would be very beneficial for designers to better link to the community context in time. As such, we would like to call for more structural work, such as design frameworks and tools to support designers intervening in this complex environment.

6. Conclusions

Social sustainability has become an increasingly important topic in design [1], because it is an important factor in creating more resilient communities [4] and realizing flourishing societies today and in the future [5]. As such, design for social sustainability investigates how civic technologies might contribute to long-term and impactful citizen participation, and community building processes [6–8]. The increased interest in design for social sustainability calls for more contextual perspectives in order to better understand the factors that might influence the design process [1]. This paper contributes to this quest by presenting an exploration of the influence of the context on the collaborative design process and four suggestions to take the contextual factors into account in design for social sustainability as a result of the contextual analyses. The insights presented in our paper are based on a retrospective case study of a design for social sustainability project in a neighborhood in The Hague, the Netherlands. In the design project, designers worked together with an industrial partner, youth worker, and teenagers to develop a serious game aiming to support teenagers in organizing activities for the local community in order to strengthen community connections. After weeks of preparation, co-creation workshops were organized to further co-design and test the developed serious game UpTrek. However, the project experienced significant pressure due to the outbreak of COVID-19 in Europe, requiring the Netherlands to go into a strict lockdown.

The Ecologies of Contestation framework [29] was used to analyze the design process on four levels (Socio-Cultural, Power, Constructed, and Value-based Ecologies) throughout three distinct periods: before, during, and after the lockdown. During these three periods, the actors collaborated to adapt the design process to the given circumstances. The Socio-Cultural Ecology revealed how the community was potentially linked to physically embedded social and cultural structures, functioning as a gateway to the community. The Constructed Ecologies extend this finding by showing the difficulties of translating the design process into a virtual and hybrid alternative, suggesting the influence of already existing social infrastructures on building new ones. The Ecologies of Power showed how all actors were dependent on each other, and all had a certain degree of power throughout the process. Values-based Ecologies further extend this finding by showing how priorities, goals, beliefs, intentions, and attitudes shifted over the design process and influenced the collaboration amongst actors, suggesting the importance of continuous alignment and addressing values.

We identified various suggestions for designers engaging in community-based design based on these results. First of all, the dynamics in the context draw attention to the temporal element in community-based design. In other words, community characteristics such as priorities, goals, intentions, meanings can change and influence the process. The influence of time should be considered throughout the design process. Designers should empower participants to reflect on the past and look into the future to attend to these changes. A specific aspect to focus on is a continuous alignment of values, which could be supported by identifying contextual elements that hold a different meaning for each actor. Identifying important contextual elements for the community can also help better connect to the community, as the community can often be seen as multilayered and dynamic.

Literature has already shown that careful consideration of the context can help design researchers increase participation and strengthen the design outcomes. This paper shows how the context could influence the design process on the Socio-cultural, Power, Constructed, and Values levels. The proposed suggestions could help design researchers strengthen their collaborative design processes to create more resilient practices.

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Abbreviations

The following abbreviations are used in this manuscript:

EoC	Ecologies of Contestation
SWO	Social Welfare Organization

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Article

The Design of Tasks to Suit Distance Learning in Emergency Education

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Abstract: Researchers are interested in task design in distance learning. This task design is critical in emergency education that uses distance learning. The present research investigated mathematics and science teachers' task design in distance learning during the emergency education due to COVID-19. Fourteen teachers participated in the research: seven mathematics teachers and seven science teachers. The data collection tool was the interview, and the data analysis tools were deductive and inductive content analysis, where the deductive analysis was based on the didactic situation framework. The research results indicated that the participating teachers could utilize the technological tools to design tasks that encourage the students' devolution regarding the activities that they carry out. Furthermore, the use of the potentialities of the distance learning platforms enabled successful communication between the participants in the didactic situation. It is recommended that quantitative research is used to investigate the ways in which the various components in the design could affect students' learning.

Keywords: task design; teachers; mathematics; science; didactic situation; emergency education; COVID-19

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1. Introduction

The recent emergency education that took place as a result of COVID-19 necessitated designing activities in order to fit the online learning to which the schools and universities turned due to the closure. This design involved the use of digital tools that helped advance students' learning, especially their engagement [1], their motivation [2] and their emotions [3]. It is interesting to study how teachers designed activities during the emergency education, and especially the aspects of learning on which they focused. In the present research, we study teachers' design of activities for online learning in the science and mathematics classroom during the emergency education forced by COVID-19.

2. Theoretical Background and Literature Review

2.1. Distance Learning in Emergency Education

Distance education has been utilized in the classroom for three decades, and it facilitates educational processes for teachers and students alike. It enables interactions between the participants in the educational processes [4], motivation for learning [5], engagement in learning [6], and the assessment of learning [7]. Lately, distance learning has flourished in the emergency education that occurred due to COVID-19 [8]. This flourishing made researchers consider this mode of learning extensively (ex., [9]). In the present research, we consider task design in distance education during the emergency education that occurred due to COVID-19.

Hodges et al. [10] distinguished between online learning, which is planned from the beginning and designed to be online, and emergency remote teaching, which is a temporary shift of instructional delivery to an alternate delivery mode due to emergency circumstances. Hodges et al. [10] described emergency remote teaching as involving the use of fully remote teaching solutions for instruction that otherwise would be delivered face-to-face, or as blended or hybrid learning. A similar argument is made by Tzafilkou et al. [11], who distinguish between 'remote' and 'distance' learning, focusing on the remote side due to the COVID-19 emergency situation. They argue that, contrary to distance learning, 'Remote Education' is defined by the geographical separation of learners and teachers. In addition, 'Emergency Remote Education' is temporal and obligatory, while distance education is an option. In the present research, we address task design in emergency remote education. As emergency remote education is only lately being studied, we address task deign in online learning below.

2.2. Task Design in Online Learning

Researchers have been interested in course and task design in distance learning (ex., [12]). Herrington et al. [13] argued that the design of an authentic online task should allow the students to make important decisions about why, how, and in what order they investigate a problem. Wang [14] proposed a set of criteria for designing videoconferencing-based tasks: practicality, language-learning potential, learner fit, authenticity, and positive impact. This set was first suggested by Chapelle [15] for CALL Task Appropriateness, where Wang ([14] fitted it to videoconferencing task design. For example, she defined practicality as "the fit between the task and the capability of the videoconferencing tool(s) to support task" ([14], p. 593).

Coman et al. [16] advised that tasks should involve teamwork to compensate for the lack of interaction in the online environment. They argue that this should be achieved with creativity in thinking when designing tasks, not only to stimulate collaborative learning but also to involve technical skills that help create and implement programs to improve interaction between students. Valverde-Berrocoso et al. [17], in a systemic review, found that diverse studies had identified nine elements for sustainable e-learning design—(a) stakeholder-centeredness: (1) a labor market-driven programming agenda, (2) a continuous improvement quality assurance system, and (3) international program standards; (b) cost-effectiveness: (4) a costing model, (5) course rationalization, and (6) a learning object repository; and lastly, (c) high operational efficiency: (7) template-based document preparation, (8) project management, and (9) an electronic project workspace.

2.3. Design of Mathematics and Science Activities

Researchers have been interested in the activity design process and in the outcome of this process. Leung and Bolite-Frant argued that "a participationist orientation would favor design with potential for students to participate in the construction of mathematical knowledge/experiences, whereby a more acquisitionist orientation would favor design that encourages the student to explore and discover established mathematical knowledge" ([18], p. 192). Thus, the educational orientation influences the activity design. Furthermore, Leung and Bolite-Frant ([18], p. 193) suggested that "[A] tool-based task design could harvest this power to shorten any distance between students' prior mathematical experiences and the intended mathematical knowledge to be learned".

Jahreie et al. [19] reported discussions on the design of science learning in the context of museums by researchers and designers. They found that the central concern for the participants in the discussion was how they could design the exhibition in a way that stimulated students' curiosity, interest, and motivation to take up the meaning-making of the scientific concepts involved.

In the present research, we will study the design of science and mathematics activities by teachers in the emergency education forced by the COVID-19 pandemic. In order to do so, we will use the didactical situations theory of Brousseau [20]. We will achieve this by focusing on the activity as a main component of the didactic situation.

2.4. Didactical Situations Theory

A didactical situation comprises three components: students, teachers, and the milieu [20]. The students interact with other students, with the teacher and with the milieu. The milieu is defined as all of the things that influence the student or are influenced by the student: "Within a situation of action, everything that acts on the student or that she acts on is called milieu" ([20], p. 9). Mackrell et al. stressed the role of activities in the didactic situation: Key aspects of a didactical situation are the mathematical problem and the choice of didactical variable values to set for the task, where the task involves learning objectives and the mathematical problem. The teacher assumes that achieving the task will cause the student to learn ([21], p. 2655).

Two components of the didactical situation framework are devolution and institutionalization. "Devolution is the act by the teacher makes the student accept the responsibility for an (adidactical) learning situation or for a problem, and accepts the consequences of this transfer of this responsibility" ([20], p. 230), while institutionalization occurs as "[the teacher] defines the relationships that can be allowed between the student's 'free' behavior or production and the cultural or scientific knowledge and the didactical project; she provides a way of reading these activities and gives them a status". ([20], p. 56). Thus, it could be said that institutionalization occurs when arriving at the socially constructed mathematical knowledge [22].

Jonsson et al. [23] intended to allow for mathematical "struggle" in adidactical situations (without teacher support) with tasks that are designed to facilitate students' own construction of solutions. In order to do so, they suggested that we consider Lithner's [24] framework of creative and imitative reasoning. In doing so, they called the second type of reasoning "algorithmic reasoning" (AR). Artigue ([25], p. 160) says that we should pay attention to "the characteristics of the milieu with which the students will interact in order to maximize the potential it offers for autonomous action and productive feedback". Thus, students' autonomy is a factor that we need to consider when we come to design activities by following the didactical situation framework.

Brousseau et al. [26] say that in the didactical contract, which is part of the didactical situation, we need to consider how the teacher takes responsibility for supporting the collective and individual activity of the students ([26], p. 155). They also talk about confirming claims in the situation or giving proofs ([26], p. 155). In addition, Brousseau and Warfield ([27], p. 163) talk about the following components of the didactical situation—making decisions, formulating hypotheses, predicting and judging their consequences, attempting to communicate information, producing and organizing models, arguments and proofs, etc.—which are adequate for certain precise projects. The present research will consider the previous constructs when mathematics and science teachers design activities for online learning in the context of emergency education.

3. Research Rationale, Goals, and the Question

3.1. Research Rationale and Goals

The design of learning materials has attracted the attention of researchers because it influences the outcomes of students' learning. Lin and Chen ([28], p. 3554) say that "Designing teaching activity for digital learning and flexibly applying technology tools are the key issues for current information technology integrated education". The previous claim is especially true in online learning in the context of emergency education. Previous studies have mainly addressed the issue of task design in online learning in the context of emergency education only, or indirectly (ex., [12]). The present research addresses this issue using a theoretical framework that has been used to consider task design in mathematics education (ex., [21]), where here we use it for online learning in the context of emergency education. The use of the didactical situation framework will allow us to utilize its various components to evaluate the design of online activities in the context of emergency education. These components are devolution, institutionalization, algorithmic reasoning, creative reasoning, autonomy, the individual activity of the student, the collective activity of the student, making decisions, and attempting to communicate information.

3.2. Research Question

What are the characteristics of the processes of the didactical situation which are considered by mathematics and science teachers in their task design during the emergency distance education?

4. Methodology

4.1. Research Design

The present research uses the qualitative methodology to study the design of online tasks by mathematics and science teachers. This use of qualitative research is in line with researchers who consider qualitative methodologies to have the potential to shape and advance important questions of educational practice and policy [29]. In order to conduct the qualitative research, we collected the data using semi-structured interviews. This use of semi-structured interviews is in line with researchers who argue that those interviews can serve the investigation of teachers' education and teachers' practices [30,31].

In the qualitative research, we used deductive and inductive content analysis. Our use of deductive reasoning depended on the didactical situation theory. Mangiante-Orsola et al. [32] argued that didactical situations can be used to answer research questions concerning teaching practices, the production of resources for teaching, and teacher development. Thus, the didactical situation theory is relevant to the present research, as it attempts to answer questions concerning teaching practices and the production of resources for teaching, when it focuses on emergency education. Deductive content analysis provided us with the categories in Table 1. We used inductive content analysis to arrive at the specific themes within each category of the didactic situation.

Table 1. Describes the participants in terms of specialty, age and specialty.

Participant	Specialty	Age	Experience
Amal	Mathematics	36	14
Salim	Mathematics	33	12
Mansour	Mathematics	16	8
Amir	Mathematics	37	15
Ahlam	Mathematics	33	13
Koltoum	Mathematics	36	12
Karima	Science	43	20
Amira	Science	35	12
Salam	Science	36	14
Sana	Science	38	15
Sama	Science	37	7
Hasan	Science	42	16
Amina	Science	34	12

4.2. Research Context and Participants

The present research is interested in the design of online tasks by ninth grade mathematics and science teachers. Fourteen teachers participated in the research: seven of them were mathematics teachers and seven were science teachers. The research participants were chosen based on convenience sampling. Etikan et al. [33] said that convenience sampling is a type of non-random sampling where the participants meet certain practical criteria, such as easy accessibility, geographical proximity, availability at a given time, or the willingness to participate. Etikan et al. [33] stressed that convenience sampling also refers to the subjects of the population that are easily accessible to the researcher. In the present research, we used convenience sampling because of the accessibility issue, as well as meeting specific criteria related to the present research, which involved mathematics or science teachers who had experience in distance learning during COVID-19.

We administered informed consent forms to the participating teachers in order for them to participate in the research. The consent form was written in a language easily understood by the participants, which minimized the possibility of misunderstanding. The participants were given sufficient time to consider participation in the research. The participants signed the informed consent forms to participate in the research, agreeing that the collected data could be used for research goals only.

The participants used distance learning, as a result of emergency education due to COVID 14, from April 2020 to June 2021.

4.3. Data Collection Tools

We collected the data by interviewing the participants regarding their design of mathematics and science activities for online learning during emergency education. The interview was semi-structured, starting from open questions such as "What activities did you use for online learning during the emergency education?" We continued with more leading questions. We tried to address all of the characteristics of the design according to the didactical situation theory. Examples of the leading questions from the interview are: "Can you describe activities that you designed and that take care of confirming or giving autonomy?", and "Can you describe activities that you designed and that take care of confirming or making a decisions"?

The interviews were held using the Zoom platform or the WhatsApp application. Each interview lasted between 40 and 50 min. The communication channel was determined by consulting the interviewee.

4.4. Data Analysis Tools

We used the deductive content analysis method to arrive at the categories associated with the participating teachers' design of tasks for online learning during the emergency education. This deductive constant comparison was based on the categories associated with learning processes that are part of the didactical situation theory. This deductive content analysis gave us the categories in the left column of Table 2. In addition, we used inductive content analysis to arrive at the themes within each category. For example, concerning the category "Making decisions", we arrived at the themes: "The problematic issue of designing a task of which the goal is decision making", "making a decision on the strategy in a proof task" and "making a decision on the strategy in a problem-solving task".

4.5. Validity and Reliability of the Analysis Method

In order to evaluate the analysis method, we used the criteria described in Lincoln and Guba [34]. The first criterion is trustworthiness. Trustworthiness has the aim of supporting the argument that the inquiry's findings are "worth paying attention to" [25]. Trustworthiness could be assessed through credibility, dependability, conformability, transferability or authenticity. Below, we address each component as it relates to the present research. We do this depending on Elo et al. [35].

4.5.1. Credibility and Dependability

In order to establish credibility, the participants in the research should be identified and described accurately. This is also related to dependability, which refers to the stability of data over time and under different conditions. Elo et al. [35] said that this could be achieved when the principles and criteria used to select the participants are clear, and when we detail the participants' main characteristics so that the transferability of the results to other contexts can be assessed [36]. Here, we decided to interview ninth grade mathematics and science teachers. Above, we described the participants in terms of age and seniority as mathematics and science teachers. In addition, we interviewed fourteen teachers to try to cover the homogeneity of the study participants and the differences between them [37].

Table 2. Categories and codes used in the deductive reasoning.

Categories of Processes in a Didactical Situation	Definition	Examples on Codes
Devolution	Accepting the responsibility of learning, solving, etc.	Investigate, explore, find out
institutionalization	Arriving at the formal conception, general solution, etc.	Formalize, conclude, generalize
Algorithmic reasoning	Following a sequence of directions to solve a problem.	Solve according to the . . . method, solve according to a sequence of steps
Creative reasoning	Fluency: Giving many solutions, ideas, etc.	Give various solutions, give frequent solutions, give many solutions
	Flexibility: Giving different solutions, ideas, etc.	Give different solutions, give different ideas
	Originality: Giving new solutions, ideas, etc.	You can use new solution method, you need to write a new solution,
Autonomy	The ability to choose a solving strategy, a learning method, etc.	Choose a solving strategy, choose your role in the group
Individual activity of the student	Activity in which the author requests the reader to work individually	Individually, each one.
Collective activity of the student	Activity in which the author requests the reader to work in a group	In groups, collectively
Making decisions	Deciding upon a learning strategy, a solving method, etc.	Make a decision, decide what strategy.
Attempting to communicate information	Arguing or discussing a scientific issue	Argue, discuss.

4.5.2. Conformability

The conformability of the data means the extent to which the findings accurately represent the information that the participants provided, and to which the interpretations of those data are not invented by the inquirer [38]. In the present research, we addressed conformability by computing the agreement between the coders. Three experienced coders coded the resulting themes and categories, searching for occurrences of sentences that indicated a design theme within each category of the didactical situation. The agreement between the coders (Cohen's Kappa coefficient), when satisfied, ensures the reliability of the qualitative coding. The computation of Cohen's Kappa coefficient resulted in 0.91 to 0.96 for the various categories related to the task design. These values are accepted for the agreement between coders.

4.5.3. Transferability

Transferability refers to the reasoning that findings can be generalized or transferred to other groups of participants or settings. The transferability increases when we give clear descriptions of the context, selection, and characteristics of participants. We tried to take care of transferability by detailing the research setting above, as well as the description of the participants. Transferability is also guaranteed when we show how we analyzed the collected data. This is described in Table 2, which includes the definition of the categories of the task design considered in the present research.

4.5.4. Authenticity

Authenticity refers to the extent to which the researchers, fairly and faithfully, show a range of realities [35]. The authenticity could suffer from the inaccurate analysis of inexperienced researchers who do not have the knowledge and skills required. Our computation of the agreement between the judges ensured authenticity. In addition, we followed, in our analysis, different qualitative studies (ex., [39,40]), which also enriched the authenticity of the data analysis.

4.5.5. Saturation of the Data Collection and Analysis

Saturation is another criterion that ensures validity and reliability. In the present research, it was arrived at during the analysis of the tenth interview, where the themes and their properties were the same as those in the previous nine interviews. Despite the recurrence of the categories, we analyzed another two interviews, which again showed the recurrence of the properties of the categories.

5. Results

5.1. Devolution Processes

The participating teachers talked about three categories of devolution processes: taking responsibility, making decisions, and autonomous processes. Below, we elaborate on each one of them.

5.1.1. Taking Responsibility

The participating teachers talked about two types of taking responsibility: taking responsibility for presenting the learning material in Zoom's main session, and taking responsibility for the group's work in Zoom Rooms.

Taking Responsibility for Presenting the Learning Material in Zoom's Main Session

Amal, a mathematics teacher, described her students' taking responsibility for presenting the topic in the main Zoom session. She said:

"In part of the lessons in Zoom, I requested one student to present the topic of the lesson after he learned it from the book. I did that to encourage the students to be present in the lesson. The lesson turned to be very successful".

Taking Responsibility for the Group's Work in Zoom Rooms

Karima, a science teacher, described her students' taking responsibility for their work in Zoom Rooms:

"During Zoom's sessions, I let the students carry out the investigative activities that I build in Zoom Rooms. I give them complete responsibility how to carry out the activity. For example, which group's member works on the PhET simulations, who writes the results and who present them".

5.1.2. Making Decisions

The participating teachers talked about two types of making decisions: making a decision on the strategy in a proof task, and making a decision on the strategy in a problem-solving task.

The Problematic Issue of Designing a Task of Which the Goal Is Decision Making

Before presenting the types, it is interesting to note that three of the participating teachers reported that they did not design a task with the goal of their students making decisions. Salim, a mathematics teacher, said: "I do not remember that I gave the students a task in which I requested them to take decisions. It could be that the students take decision in Geometry, but I did not design such task".

Making Decisions on the Strategy in a Proof Task

Mansour, a mathematics teacher, described what he understood by task design which includes making decisions:

"Usually, the student takes decision when he comes to a problem designed as proving a claim. For example, when coming to prove that two edges are equal, the student has to decide which theorem of congruent triangles to use. This decision also depends on the pair of triangles on which he decides to do the congruence. The students solved these problems during Zoom's main session, or in Zoom Rooms".

Making Decisions on the Strategy in a Problem-Solving Task

Koltoum, a mathematics teacher, described her task design, saying: "I designed activities, during the main session of Zoom, in which I demonstrated for the students how to take decisions on the strategies they use to solve a mathematical problem. For example, whether to use the rule or the factorization to solve a quadratic equation".

5.1.3. Autonomous Processes

The participating teachers talked about four types of autonomous processes: autonomous processes through discussion, autonomous processes through discovery, autonomous processes through games, and autonomous processes through practice.

Autonomous Work through Discussion

Amir, a mathematics teacher, considered the whole-class discussion as task-design that encourages the autonomous work of the students: "In the design of activities, we used the interactive board for letting the students develop their knowledge. The students worked alone, and then we discussed their work. All the students participated in the discussion and understood the mathematical topic. I almost did not interfere in the discussion. It was the students' own engagement".

Autonomous Work through Discovery

Amal, a mathematics teacher, considered the design of discovery learning as encourages the autonomous work of the students. Amal said:

"The students work autonomously when you let them learn by discovery. One activity that I designed for the students during the online learning was the triangle heights activity. The activity consisted of a set of questions that advanced in complexity. I put this activity in the classroom site. It requested the students to draw, with GeoGebra, an acute-angles triangle and then draw its heights. This question was followed by one that requested the student to write a conclusion about the heights in an acute-angles triangle. Afterwards we moved to the right-angle triangle, doing the same steps, and then to the obtuse-angle triangle".

Autonomous Work through Games

Salam, a science teacher, described how the Genially application helped her to design an activity that enabled her students to learn autonomously through games. She said:

"I designed game activities, such as the 'Treasure Hunt' activity and the 'Escape Room' activity. I built these activities in the 'Genially' application. This application can transform data and information into images and graphics that can be clearly understood. It contains several free, attractive and modern templates to prepare presentations and live games such as (Ladder and Snake, Treasure Island...). We can use these templates to design games".

Autonomous Work through Practice

Salam also used technological applications to design an activity that allowed her students to practice autonomously the learned materials. She said:

"After I taught the students the subject of ions in chemistry, they had to practice a lot on it. Because the subject of ions needed to be practiced a lot by the students, I built an activity in Genially application. I did not want to give the students regular worksheets all the time, because the students will get bored, so I used Genially. This way, the student solves, and if his answer is wrong or true, this will appear through the application, and therefore the student either takes a step forward or corrects his mistake. This will enable the students to advance a step within the application. Thus, the student works independently, which makes him develop independence".

5.2. Institutionalization Processes

The participating teachers talked about three types of institutionalization processes in their task design: processes in the conclusions at the end of the discovery learning, processes on the sites that feature the learning materials, and processes in the formal textbooks.

In the Conclusions at the End of the Discovery Learning

Ahlam, a mathematics teacher, said: "We usually arrived at the generalization of the topic in the whole-class discussion in the Zoom session after the students worked in groups in Zooms' rooms, where they explored the mathematics topic".

On the Sites That Feature the Learning Materials:

Amira, a science teacher, said: "When I gave the students an asynchronous task, I requested them after solving the investigative task to verify their conclusions by looking for scientific material on suitable sites".

In the Formal Textbooks

Amina, a science teacher, said: "In asynchronous distance learning, the textbook served us to arrive at the formal conclusions of the science topic. I asked them to read the formal conclusions from the textbook, so that they use the exact scientific formulation".

5.3. Algorithmic Processes

The participating teachers talked about two types of algorithmic processes in their task design: processes which are algorithmic in structure, and those which are algorithmic in actions.

Activity of the Type 'Algorithmic in Structure'

The activities of the type 'algorithmic in structure' included project-based activities, where these activities conditioned the work in the project. Amal, a mathematics teacher, described one of these activities:

"We were searching for different tasks and activities, for example one of the activities with which I engaged the students was projects. In designing the activity, I took care that the text included what was needed from each group. It also included the links that they could use to carry out the project, as well as the final product of the project".

The project, as an activity, includes some freedom for the students regarding the roles of the members in the group. This is especially true in distance learning, where this learning happens using distance communication tools. Thus, in this case, the algorithmic process refers to the structure of the activity, as perceived by the participating teachers.

Activity of the Type 'Algorithmic in Actions'

The activities of the type 'algorithmic in actions' included the sequence of actions that the students were requested to perform. One such activity was described by Sama, a science teacher:

"Among the topics that I taught, we had the topic of "reagents", a topic related to acids and bases. The activity that I developed required to do a home experiment in which the student investigates whether certain substances are acidic or basic. Of course, before that, I explained to the students about the subject, I sent them materials to read as a scientific background on the subject, and then I sent the students a paper explaining the series of the steps of the experiment. I prepared the materials and presented them to the students from the school laboratory, and the students did the experiment at home according to the steps given to them".

5.4. Creative Processes

The participating teachers talked about four types of creative processes: the creativity of the student in the regular activities, the creativity of the student in the enrichment activities, the creativity of the student in the fun activities, and the creativity of the teacher in the online setting.

The Creativity of the Student in the Regular Activities

Amir, a mathematics teacher, described a problem that he gives as a regular activity in the main Zoom session:

"I gave the students a problem that required them to think creatively. This problem requested the students to write a quadratic function that intersects the x-axis in two specific points. I wanted the students to be aware that different functions could satisfy the conditions".

The Creativity of the Student in the Enrichment Activities

Salim, a mathematics teacher, described an enrichment activity in which his students engaged in creative mathematics learning:

"During learning the topic of the function slope, it was important to give the students an enrichment activity. The students solved an activity using GeoGebra, where they were requested to draw a flower in different ways. The students were requested to draw this flower in GeoGebra using straight lines and find the slopes of the lines and the relationship between them. In this activity, the students drew any flower that they wanted. Thus, they had the freedom to draw the flower, which made each one attempt to draw more than one flower, and some succeeded to do so. The students described their drawings as creative".

The Creativity of the Student in the Fun Activities

Sana, a science teacher, described a fun activity in which her students were engaged creatively:

"I built an activity for the students using the table of elements. The elements' symbols in chemistry are in Latin, so the students find them difficult. The activity requested the students to form meaningful sentences from these symbols. They created sentences such as "Eid Fitr Mubarak", or "Stay at home', where the last sentence fits the period of COVID-19".

The Creativity of the Teacher in the Online Setting

Amira, a science teacher, described an activity that she considered to imply her creative thinking:

"I want to tell you about an activity that I designed for the start of the lesson. This activity intended to attract the students to distance learning. I designed an activity called "Chemical Wisdom", which is related to the topic. For example, when I taught the students about the table of elements, I took into consideration that the elements in the same column feature common characteristics. So, I formulated the wisdom: Be strong as iron, be radioactive as uranium, be positive as the proton, do not be negative about any element. We started the lesson by saying the wisdom. The students were very pleased and every day they waited for me, entering the Zoom platform before the start of the class, so that they would not miss the chemical wisdom of the day. The design of the activity took advantage of different applications that helped display the wisdom in a beautiful way, such as 'Emaze'".

5.5. Individual Work

The participating teachers talked about three types of individual work: individual work in exploration activities, individual work in homework, and individual work in summary tasks.

Individual Work in Exploration Activities

Ahlam, a mathematics teacher, described an exploration activity with GeoGebra: "I designed activities that requested the students to work individually on exploration activities, as using GeoGebra to find the relation between the graph of a parabola and the parameters of the quadratic equation".

Individual Work in Homework

Ahlam, a mathematics teacher, reported the use of individual work in homework: "The homework was in general individual. It consisted of questions of different level on the material that the student learned in the class".

Individual Work in Summary Tasks

Hasan, a science teacher, described his use of individual work in summary tasks: "At the end of the unit, I gave the students an activity that requested them to write a summary of the unit using the presentation that they chose: PowerPoint, Word, electronic book, Nearpod, etc".

5.6. Collaborative Work

The participating teachers talked about two types of individual work: collaborative work to solve difficult problems, and collaborative work to address scientific ideas outdoors.

Collaborative Work to Solve Difficult Problems

Amir, a mathematics teacher, said: "when the problem that I gave the students was not an easy one, I designed that the students solve this problem collaboratively in Zoom Rooms. This helped them discuss it and I could watch this and interfere when needed".

Collaborative Work to Address Scientific Ideas Outdoors

Sana, a science teacher, described her attempts to provide her students with collaborative work during the emergency education:

"I did not like that my students, during the distance learning period in light of the emergency situation of Corona, were deprived of any activity they were accustomed to in face-to-face learning, such as collaborative learning. After the students had learned most of the topics required of them, I thought I would give them an opportunity to investigation. So, I decided that we should conduct a collaborative investigation activity, which we called it "Science through the Eye of a Camera". What does it mean? I started thinking what the things were that all students loved and indulged in most of the time? I found that they were mobile phones, cameras, photography and publishing".

When Sana was asked by the reviewer to elaborate, she said:

"I took advantage of this idea and announced the "Science through the Eye of a Camera" competition. The competition was presented and published on WhatsApp for groups of students' parents to get an idea about a topic, and we encouraged the students that the winning group in this project would have a bonus. There was a jury to judge who was the group who performed the best work and the best investigation. We divided the students into groups to work collaboratively and delegated them to go to photograph a phenomenon in nature and then tell us about it. They were also requested to explain why this phenomenon appeared in the winter like the "rainbow" phenomenon, based on research on the phenomenon and by fetching information about it. We sent rules and specific instructions for students to work according to and announced the day of the competition. We used an application called "Art steps" to design this activity. This tool allows to create three-dimensional exhibitions for specific projects such as displaying pictures, paintings and models".

5.7. Communication

The participating teachers talked about four types of communication: communication using mobile social networks, communication using Zoom rooms, eye communication in Zoom sessions, and teachers' communication in the Google Classroom.

Communicating Using Mobile Social Networks

Amina, a science teacher, reported that in order to encourage her students' communication during the emergency education, she built a WhatsApp group. She said: "I built a WhatsApp group for each class. The students used this group to communicate about everything related to mathematics. Sometimes I used the WhatsApp to put a question that is difficult. I took into consideration that the students would inquire about this question, about the content of the question, or about strategies to solve the question".

Communication Using Zoom Rooms

Samira, a mathematics teacher, reported that she used Zoom Rooms to facilitate her students' discussion of new topics. She said: "I used Zoom Rooms for the students to investigate together a new topic that needed discussion to understand. For example, when introducing the quadratic function".

Eyes Communication in Zoom's Sessions

Saeed, a mathematics teacher, pointed out that communication is interaction, and that eye interaction is very important to the learning of the students. He said:

"The student should not be just listening, why? Because if you make the students just listen, they will be lost. The camera must be on, the student must be active in the lesson. During the explanation, the student is asked to explain specific points. In the activities that I design, the students are the ones who lead the lesson. You as a teacher give the initial content and then conduct the discussion among the students. In order to encourage the interaction between the students, we used different applications: the interactive whiteboard, live worksheets and FullProof".

Teachers' Communication in the Google Classroom

Amira, a science teacher, described her communication with other teachers in the Google Classroom: "There is a group dedicated to science teachers, I put each task that I designed in the classroom, and every other teacher also puts his designed tasks there. So, we have a store of tasks and activities".

Table 3 describes the frequency of the mathematics and science teachers mentioning each theme and category.

Table 1 shows that the mathematics and science teachers, when designing tasks in remote emergency education, were concerned with autonomous, individual and communicational processes more than other processes. In addition, the mathematics and science teachers did not differ regarding the didactical situation processes that they utilized in their online task design.

Table 3. Frequency of the mathematics and science teachers mentioning each theme and category.

Category	Theme	MT	ST	All
Taking responsibility	Taking responsibility on presenting the learning material in Zoom's main session	1	1	2
	Taking responsibility on the group's work in Zoom's rooms	5	4	9
Taking decisions	The problematic issue of designing a task whose goal is decision making	3	3	6
	Taking decision on the strategy in a proof task	3	2	5
	Taking decision on the strategy in a problem-solving task	1	1	2

Table 3. *Cont.*

Category	Theme	MT	ST	All
Autonomous processes	Autonomous work through discussion	5	6	11
	Autonomous work through discovery	5	6	11
	Autonomous work through games	2	3	5
	Autonomous work through practice	3	3	6
Institutionalization processes	In the conclusions at the end of the discovery learning	6	5	11
	On the sites that have the learning materials	1	1	2
	In the formal textbooks	1	2	3
Algorithmic processes	Activity of the type 'algorithmic in structure'	3	4	7
	Activity of the type 'algorithmic in actions'	3	5	8
Creative processes	Creativity of the student in the regular activities	3	4	7
	Creativity of the student in the enrichment activities:	2	2	4
	Creativity of the student in the fun activities	2	3	5
	Creativity of the teacher in the online setting	4	4	8
Individual work	Individual work in exploration activities	6	5	11
	Individual work in homework	7	7	14
	Individual work in summary tasks	4	3	7
Collaborative work:	Collaborative work to solve difficult problems	5	5	10
	Collaborative work to address scientific ideas outdoors	5	4	9
Communication	Communicating with mobile social networks	3	3	6
	Communication with Zoom's rooms	6	7	13
	Eyes communication in Zoom's sessions	6	6	12
	Teachers' communication in the Google Classroom	2	2	4

MT = mathematics teachers; ST = science teachers.

6. Discussion

The present research came to investigate the design processes of mathematics and science tasks during online emergency education. In order to do so, we used the didactical situation framework and looked at some of its components. Below, we discuss our findings in relation to the different components of the didactic situation.

6.1. Devolution Processes

The research results indicated that the devolution processes were of three types: taking responsibility, making decisions, and autonomous processes. These processes indicate that part of the learning that occurred in the mathematics and science classrooms, in the time of the emergency education, was performed in a social environment that encouraged democratic practices such as autonomy and making decisions ([41,42]). In addition, this environment encouraged digital citizenship as taking responsibility [43]. It is argued that teachers, when confronted with emergency education, could also manage task design in distance learning. This utilization depended on different factors, and one of the main factors was the use of resources. Autonomy, for example, was enabled due to the utilization of digital resources. The participating teachers reported the use of the whiteboard, GeoGebra, and Genially to enable their students to be autonomous. They also reported the use of PhET simulations in tasks in which the students took responsibility for their execution. Zoom Rooms enabled these social processes, especially the students' interaction [44].

6.2. Institutionalization Processes

Institutionalization processes had the goal of arriving at scientific relations, as accepted by the professional community. Here, the teachers, in their design of tasks that encouraged institutionalization processes, used digital tools such as internet sites, as well as non-digital resources such as the regular textbook. Thus, the use of tools here in the design of tasks was blended. The teachers were part of emergency education, so they used digital and non-digital resources. It could be that their past use of non-digital resources made them utilize them in the new mode of their students' learning. Here, this is not strange, as the textbooks included formal content.

6.3. Algorithmic and Creative Processes

The participating teachers reported that they designed tasks that used algorithmic and creative processes. These two processes could be considered two end points of an interval that represents learning processes [23]. We claim that the explorative processes that were part of the learning experience in the mathematics and science classes during the emergency education were part of that interval, lying between the algorithmic and the creative processes. Thus, the learning processes in the distance education during the COVID-19 pandemic were of a different type, which could indicate the potential of distance education—even in times of emergency—to enable different types of learning processes. This points at distance education as having the potential to be part of students' learning in regular times. Other studies reported that, with support from parents and teachers, students could cope with distance learning [45], which means that it is possible to benefit from distance learning even in regular times.

6.4. Individual and Collaborative Work

The teachers designed tasks based on individual work for exploration activities, homework and summary tasks. In doing this, they used mainly GeoGebra and presentation applications. In addition, they designed tasks based on collaborative work for the solution of difficult problems, and for working with scientific ideas outdoors. The support of collaboration for problem solving has been reported in the literature. For example, Adolphus et al. [46] reported that there was a significant difference in problem solving abilities between students who participated in collaborative learning and those who used the conventional method. This difference was in favor of the group who used collaborative learning. In addition, designing tasks based on collaborative work for working with scientific ideas outdoors has been reported in the literature. For example, Daher and Baya'a [47] reported the work of middle school students on outdoor mathematical activities using mobile devices.

6.5. Communicational Processes

Communicational processes were used by the participating teachers for two goals. The first was to make students' learning effective, and the second was to provide the teachers with resources. In our case, we argue that the teachers who participated in the present research could manage the distance learning communication using distance platforms, specifically mobile social networks, Zoom Rooms and the main Zoom session. This ability to manage communication is important for the success of distance learning, as the researchers pointed toward collaboration, enabled by communication, as enabling or hindering students' building of knowledge. Klimova et al. [48] reported that the lack of social contact—which included the absence of collaboration between the teacher and students, and between the students themselves—resulted in little sharing and building of knowledge and experience by the students.

7. Conclusions, Recommendations and Limitations

This study reported the task design of mathematics and science teachers during the emergency education imposed on schools due to COVID-19. Using the didactic situation framework, we analyzed this design by focusing on different aspects of the didactic situation. The research results indicated that the participating teachers managed their teaching in the time of emergency education by different means. First, they attempted to use different digital resources, but sometimes they also used regular resources, such as the regular textbook. Second, the teachers used strategies that helped to provide the students with the devolution of their learning; this devolution was investigated in the present research by considering autonomy, taking responsibility and decision making. These constructs are important as practices in a democratic society [49]. As such, distance education—even that which occurs in emergency education—could support an educational environment that encourage democratic practices, and could thus prepare the students for democratic society. This is in line with Martyushev et al. [50], who said that students often view online communication as a safe environment for self-expression and learning.

The present research results indicate that the mathematics and science teachers were concerned with autonomous, individual and communicational processes, more than other processes. At the same time, they were less concerned with making decisions as an educational practice. These results could be related to the socio-cultural aspect of education [51]. Although the teachers were concerned with autonomy, they were not interested in making decisions as a distinguished practice. The ministries of education should place emphasis on making decisions as a classroom practice that prepares the student—together with other practices, such as autonomy—for democratic life. In addition, the mathematics and science teachers did not differ regarding the didactical situation processes that they utilized in their task design, which could be due to the similar socio-cultural conditions under which they worked, and to the fact that both teach scientific disciplines. Future research is needed to study task design, in emergency education, by the teachers of the humanities and social studies.

The number of teachers who participated in the present research, fourteen, is acceptable because it enabled us to reach saturation [52], but quantitative research that depends on the present study is needed to give a broader picture about the task design practices of the whole population of mathematics and science teachers. This broad picture is related to different quantitative aspects, such as the difference in design processes according to the teachers' experiences in technology integration in general, and in distance education in particular. In particular, quantitative research is needed to investigate how the various components in the design could affect students' learning.

In addition to the above, the present research addressed qualitatively the task design of mathematics and science teachers. Future studies need to address, using qualitative methods, task design by teachers of other disciplines such as social studies or languages.

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sustainability

Article

Social Innovation Design and Sustainability of Youth-Led Bamboo Craft Brand in Zhushan Township, Taiwan

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Abstract: Various brands of bamboo crafts created by youths have emerged in Zhushan Township, Taiwan. With the special bamboo materials available in Zhushan Township as their core, these brands have created different types of social innovations through their management, design, and mechanical knowledge. The results indicate the following: (1) The youths advocate for causes such as the preservation of culture, mutually beneficial situations, sustainable local development, and environmentally friendly lifestyles. The youths proposed innovative solutions for these causes, such as establishing a guesthouse, revitalizing unused space, creating opportunities for dialogues, developing bamboo-based environmentally friendly products, and holding local activities; (2) the youths constructed a model for internal cooperation and enhancement, revitalization, and marketing Zhushan Township; (3) the youths advocated for various social values, utilized social capital, and proposed innovative solutions through diversified participation and the creation of new relationships, allowing different communities to generate a group dynamic to resolve social problems and achieve sustainability together. This study aids in the facilitation of sustainable management of township micro-enterprises by innovating products and service modes through social capital and social value. At the same time, local and common social innovation modes are connected to provide a reference for the social innovation of micro-enterprises.

Keywords: Zhushan Township; youth-led bamboo craft brand; social innovation design; sustainability

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1. Introduction

Before the 1980s, Zhushan Township in Taiwan was once an important town where 70% of the population was engaged in the bamboo industry economy. After industrial transfer and population migration, the population decline slowed down in the recent three years, from −0.99% to −0.28%, and the town has been faintly attractive [1]. In 1994, the Ministry of Culture initiated the community building policy, and the farmers' associations and town offices in bamboo-producing areas set up bamboo craft training courses one after another to train local bamboo art technical talents, drive the local economic production capacity, and beautify the hometown environment [2]. When the 921 earthquake occurred in Taiwan in 1999, Zhushan Township was the hardest hit area, which led to the increase in population migration and promoted regional activation and industrial reengineering through community building [3]. In 2002, the bamboo craft industry encountered a new opportunity, and the Ministry of Culture launched two five-year Cultural and Creative Industries programs in succession to boost the craft industry by design [4]. In 2003, UNESCO passed the Convention for the Protection of Intangible Cultural Heritage. Consequently, the inheritance of bamboo art was paid more attention [5]. In 2005, the National Taiwan Craft Research and Development Institute (NTCRI) promoted the Local Craft Characteristic Counseling-Community Craft Support Plan, in which craftsmen developed local craft products together with community residents, university teachers, and students to form local industries. From 2008 to 2013, the NTCRI and Taiwan Creative Design Center jointly launched the five-year Craft Fashion Yii Plan, which promoted the whole bamboo process design to the international stage. In 2019, Zhushan Township, as one of the 134 townships promoted by Taiwan's Regional Revitalization Policy, attracted more resources for youth entrepreneurship and the local economy.

The Forestry Bureau of Taiwan cooperated with the Industrial Technology Research Institute (ITRI) to improve the performance of bamboo materials. Through anti-corrosion and stratification technologies, the tolerance of bamboo can be improved, and its strength can even be close to steel. In this way, bamboo can be used to build roof beam structures [6]. The Forestry Research Institute mainly focuses on bamboo forest management and resource investigation, bamboo forest carbon storage research, counseling bamboo farmers to build bamboo charcoal kilns and produce bamboo charcoal, and bamboo processing and application [7]. Thanks to the use of bamboo as an ecological material, it is possible to implement eco-innovations and join the closed-loop economy [8].

In the past five years, the old, middle-aged, and young generations who worked outside, returned home to start businesses one after another. People from different countries and regions traveled to Zhushan. In addition, universities, governments, non-profit organizations, and other institutions came to Zhushan to carry out social practices, of which more community residents participated. Although the actions of the youths have been affirmed by society, there are still many obstacles for young people in starting businesses in rural areas, such as breaking old ideas, tackling key technical problems, and restricting marketing channels. So, how do they overcome difficulties, launch social innovative design actions, and promote the concept of sustainability? In light of the five youth-led bamboo craft brands of Zhushan Township, the research purposes are as follows:

(1) Analyze the content and characteristics of social innovation design and sustainability of these brands;
(2) Analyze the social innovation design and sustainable mode of these brands;
(3) Analyze the relationship between the social innovation design and sustainability of these brands.

This paper discusses the social innovation design and sustainability of Zhushan's five active youth-led bamboo craft brands. Further, it provides a reference for the sustainable development of micro-enterprises in villages and towns, participating in industrial innovation and social innovation with design, and boosting local revitalization.

2. Literature Review

2.1. Bamboo Craft and Youth-Led Bamboo Craft Brand in Zhushan

Faced with the problem of sharp shrinkage of the bamboo industry since the 1980s, Zhushan Township, an important place of bamboo craft, and Taiwan craft management units have made great efforts in the inheritance and development of bamboo craft, offering a large number of courses and cultivating bamboo artists. In addition to skill inheritance, the NTCRI's bamboo talent cultivation course focuses on product development, bamboo application, technology research and development, and brand marketing [9]. The Taiwan Forestry Research Institute used surplus bamboo materials to develop special paper products. This technology can promote recycling in the bamboo industry and provide a reference for pulp and paper mills and other industries in the production, research, and development of special papers [10].The Forestry Bureau studied the influence of bamboo forest composition, new bamboo growth, and forest land regeneration and applied modern machinery [11].Through resource inventory and cross-border integration, the Townway Cultural and Creative Corporation introduced cultural creativity to local areas, constructed a diversified and all-around development mechanism, stimulated residents to participate in local affairs, encouraged young people to return home, and established local brands [12]. Through the business model, social enterprises make use of the ecosystem to provide diversified resources, make the overall operation more effective, and save money—at the same time [13], rediscover themselves and places, and move towards the practice of reciprocal value [14].

2.2. Social Innovation Design

2.2.1. Origin and Connotation of Social Innovation

Eleanor Shaw pointed out that the practice of social innovation began in Britain in the 19th century when a few charitable entrepreneurs noticed that the improvement of the working environment, education, and cultural life helped enhance the well-being of employees [15]. In 2003, the OECD considered that social innovation aims at social and economic problems and improves the quality of life of the people and the general public by rediscovering and giving new services and solutions [16]. Social innovation is an innovative model with scientific and technological needs, platforms, and organizations [17]. Schumann et al. divided organizational innovation into product innovation, process innovation, and program innovation [18]. Additionally, economist Harvey Brooks stated that organizational innovation should come first [19].

In 2007, British economist Geoff Mulgan and others believed that "Social innovation" is defined as "innovative activities or services motivated by meeting social needs, whose main purpose is to affect the entire society." [20] Defined by James Phills, Professor of Stanford Social Innovation Organizational Behavior in 2008, "*A novel solution to a social problem that is more effective, efficient, sustainable, or just than existing solutions and for which the value created accrues primarily to society as a whole rather than private individuals*" [21]. Social innovation involves the interplay of resources, environmental factors, and interactions between actors [22].

The characteristics of social innovation [23]: (1) comprehensiveness; (2) openness; (3) pluralistic participation; (4) decentralization. The so-called decentralization is to give full play to the initiative and creativity of the bottom-most organization and distribute the decision-making power to the subordinate organizations [24]; (5) super social responsibility; (6) relevance [25]. Social innovation is the combination and recombination of social practices [26]. Putnam believes that social capital includes networks, norms, and trust in social life so that participants can act together and achieve their goals effectively [27]. Onyx and Bullen pointed out that social capital includes participation, trust, network, reciprocity, and norms [28]. Many companies with little infrastructure, regulatory authority, or money to respond to newcomers' immediate needs or make longer-term integration investments [29].

2.2.2. Definition and Content of Social Innovation Design

Victor Papanek deemed that designers should pay attention to the needs of society, the environment, and design for 90% of the general public in the world [30]. Tim Brown of IDEO, a design innovation company, emphasized that design thinking is optimistic, constructive, and experiential in nature, which can meet people's needs for products and services [31]. Social innovation is to apply knowledge and meet the needs of the public. Meanwhile, the operation method can obtain social resources, social support, and promotion [32]. As the concrete implementation of social innovation is through social design, it can be seen that social innovation design uses social resources and knowledge to meet the needs of society and put forward innovative schemes.

Dr. Ezio Manzini stated, "Social innovative design is all the activities that professional design can implement to activate, maintain and guide society towards sustainable development". Only on the basis of establishing contacts can small local organizations have a large-scale impact. Under the positive influence of the network age, there is another possibility to avoid structural bureaucracy; that is, through horizontal and vertical connections [33]. In the connection strategy stage, it is necessary to achieve scale improvement through connection, where design schools play an important role. He argued that the emerging trend in design is gradual networking [34], which shows that design schools can become cultural institutions for social innovation. The potential of design schools may be a collaborative social resource, becoming an active key, and having a creative role in sustainable development [35]. The development and popularization of the internet provides a new channel for rural service innovation, showing the following characteristics [36]:

(1) diversified service roles [37]; (2) localization of service content and resources [38]; (3) network communication of service vision. At present, villagers lack willingness and have a weak perception of the value of rural culture. Economic development has become the biggest factor in guiding villagers to participate in cultural revitalization [39], which is necessary to spread the vision [40]. A spike in community solidarity and a resurgent appetite for cross-stakeholder solutions based on multidisciplinary know-how could make this a historic opportunity for social innovation to strengthen community resilience [41].

2.3. Sustainability

Sustainable development is defined as a development model that can meet our present needs without damaging future generations' ability to meet their needs [42]. In September 2015, the United Nations issued Transforming Our World: The 2030 Agenda for Sustainable Development through the agreement of SDGs (Sustainable Development Goals). This policy plans 17 sustainable development goals, taking into account three major aspects: economic growth, social progress, and environmental protection [43]. In 2004, Dr. Hua-Shan Guan sorted out the essentials and practices of a sustainable community mentioned by many scholars (Kline, Hancock, Roseland, Barton) and summarized them as follows: (1) economic sustainability: having the ability to maintain its own economic development, green business, create new products, update the operation mechanism of the community, and achieve its own economic balance operation; (2) social sustainability: paying attention to the organization and operation of the community, establishing the consensus of residents for the community, establishing the mutual benefit mechanism of neighboring areas, and improving the local autonomy and social responsibility of the community; (3) environmental sustainability: the management and application of community environmental practices, including waste reduction, recycling, local resource management, etc. [44]. The DfSS framework specifically encourages designers to create solutions that are not just user-focused, but are systems-focused. Rather than focusing on how products can solve people's needs, we draw attention to how the entire product lifecycle (including design, manufacture, use, and maintenance) can maximize social impact [45].

2.4. Social Innovative Design and Sustainability

The shift to a low-carbon community needs the transformation of government functions, improvement of a community system, and citizens' participation [46,47]. Social innovation realizes the harmonious relationship among people, the environment, and society through pluralistic participation [48]. People and designers design together and participate in constructing a low-carbon community, which can not only meet residents' needs to the maximum, but also promote community development [49]. Designers should re-understand their value, understand the inner spirit and meaning of culture, fully communicate with the locals, and jointly develop necessities suitable for local life, circulating commodities, and even international products with a high added value [50]. Chang Wen-shan, a design scholar in Taiwan, believed that SDGs correspond to USR in Taiwan, and through the companionship and squatting of university teachers and students in the community, it will produce a closer sense of connection and carry out social practice programs for local problems. These will form a testing ground for sustainable management that practices commercial, social, cultural, and ecological values [51]. Chris Ryan, an expert in the field of social innovation, stated that "the distributed system model has attracted increasing attention, and it is regarded as a way to build a sustainable economy" [52]. He further remarked that "distributed models place and arrange infrastructure and critical service systems near resource and demand points. Individual systems can operate independently and adjust themselves, while also connecting with larger local, regional, or international networks" [53]. Distributed systems learn from problems and are more resilient than mainstream vertical systems [54]. Moreover, the necessary condition for a sustainable society is recoverability [55].

3. Methods

The four elements of qualitative research are building relationships with the subjects, sampling, data collection, and data analysis, all of which determine the value and validity of the conclusions of the research [56]. The subjects of this study were five bamboo craft brands created by young entrepreneurs in Zhushan Township, namely, Townway Cultural and Creative Corporation (hereinafter Townway), Yuantai Bamboo (hereinafter Yuantai), KYOU Bamboo Design (hereinafter KYOU), La-boos, and Bamboo-Lai Culture & Creation (hereinafter Bamboo-Lai). The leaders of these brands met at the Spotlight Meetup activity held by Townway, which cultivated their new start-up brands. They have cooperated to revitalize Zhushan through social connections based on design. The 5 years of their cooperative relationship was also a period in which Zhushan experienced an eruption of collective power used to generate social influence.

3.1. Research Procedure and Methodology

The 5-year research process spanning from September 2016 to June 2021 comprised the following three steps: (1) preliminary preparation and field observation: documents were analyzed to collect textual information regarding the topic, and several field surveys were conducted to screen samples and identify the subjects; (2) observation and data collection: observation and interviews were conducted with stakeholders of the five youth-led bamboo craft brands, such as the leaders of the brands, bamboo craftsmen, college teachers and students, and local residents; (3) data analysis and collection: grounded theory was used to code, analyze, and organize the data, followed by an evaluation using social innovation design and sustainability theories derived from the literature; the goal was to study the social innovation design of youths in the bamboo craft industry and its sustainability.

3.2. Research Data Collection: Observation Method and Interview Method

From September 2016 to June 2017, the author, a student, used participant observation to study the subjects and their environment, drawing from the long-standing collaboration between the author's school and Zhushan to naturally establish amicable relationships with the subjects. The author gradually established a relationship of trust and understood the context of the research through participation in several public events held by the brands and exchange and dialogue with related personnel. In-depth investigations began after 1 year of preliminary preparation and observation. From March to December 2017 and from September 2018 to June 2019, the author entered the field multiple times and actively participated in various activities related to the brands. The events were documented through images, audio recordings, and field notes that were used as first-hand observational data and, subsequently, organized. Table 1 lists the main events held by the young entrepreneurs from September 2016 to June 2019.

This study also conducted interviews with 15 key figures in the youth-led bamboo craft start-ups, including those with the stakeholders of the five brands. Each figure was interviewed approximately 1–3 times, and each interview lasted approximately 1 to 2 h. The interviews were open-ended, semistructured, and were conducted between May 2017 and May 2019. The interviews revolved around the brands' entrepreneurial process, ideas, product innovations, participation in events, cooperative projects, and marketing channels. The interviews were conducted with key figures knowledgeable about social innovation behavior and sustainability to achieve saturation, as shown in Table 2.

Table 1. Summary of main events held by the youth-led bamboo craft brands in Zhushan from 2016 to 2019.

Time	Event and Venue	Contents
14 November 2016	Store survey: Beyoung Garden and Yuantai. Venue: Zhushan Station, Taisi Bus Station.	Observation of everyday operations of the stores; understanding of the products and consumers.
31 March 2017	Workshop guiding young entrepreneurs in their design of services led by Professor from National Yunlin University of Science and Technology (YunTech). Venue: Bamboo Nest Class.	Implementation of a local revitalization guidance program; the role of YunTech post incubation.
7 May 2017	Forum on regional revitalization; reversing design; shaping the features of a town of tea and bamboo. Venue: Beyoung Garden.	Collaborative discussion about regional revitalization between companies, organizations, YunTech, governments, the Ministry of Education, and residents of Zhushan and Lugu.
19 May 2017	Spotlight Meetup activity: workshop on channel and industry guidance by Bright Ideas Co., Ltd. Venue: Bamboo Nest Class.	Improving the products of the young entrepreneurs; curatorial preparation; counseling on brand marketing strategies.
15 October 2017 23 October 2017	Survey of young entrepreneurs' workplace. Venue: stores and manufacturing plants of five brands.	Understanding the young entrepreneurs' work environment, jobs, production processes, and marketing channels.
1 December 2017	Reversing Design: Regional Revitalization (a special joint exhibition at the end of the program). Venue: Songshan Cultural and Creative Park, Taipei.	Young entrepreneurs presenting products, social values, and local exports.
10 May 2018 23 May 2018	Store survey: five young entrepreneurs and other key figures in the bamboo craft industry. Venue: Zhushan Station (Taisi Bus Station) and surrounding area.	Evolution of young entrepreneurs' management and ideas and planning for future development with the Spotlight Settlement ecological mechanism.
6 October 2018	Town Fair in Zhushan. Venue: Zhushan Station, Taisi Bus Station.	Trial run of Regional Revitalization Festival 1 month before; DIY bamboo weaving; exhibition of the brands.
26 October 2018	Spotlight Meetup activity: preparation for Zhushan Culture Regional Revitalization Festival. Venue: Bamboo Nest Class.	Presentation by Pu Yuan and Bamboo-Lai; the representative of Yuantai explained the preparation for Revitalization Festival in Zhushan with the help of local residents.
10–11 November 2018	Zhushan Culture Regional Revitalization Festival. Venue: Zhushan Station (Taisi Bus Station).	Events such as handicraft workshops and local cuisine presentations; participation of young entrepreneurs, arts and cultural groups, government officials, residents of Zhushan, and tourists from other regions.
28 December 2018	Spotlight Meetup activity. Venue: Bamboo Nest Class.	Teachers and students from the Department of Industrial Design of YunTech shared their design projects using recycled bamboo; presentation by Townway about Digital Townee program.
10 March 2019	Store survey: five young entrepreneurs in the bamboo craft industry. Venue: Zhushan Station (Taisi Bus Station).	Young entrepreneurs' product and brand management and event organization; local residents and local organizations.
13 May 2019	Announcement by Professor of YunTech. Venue: conference room in Design-led Innovation Center of YunTech.	Strategy for cultivating young entrepreneurs in Zhushan between 2017 and 2019.
9 June 2019	Survey of Taisi Bus Station Activation project. Venue: Zhushan Station (Taisi Bus Station).	Observing tourists, local residents, and the operations of Bamboo Life Cultural Association and Building a Mountain City.

Table 2. Summary of interviews with 15 key figures from 2017 to 2019.

Brand	Identity Code	Background
1. Townway	Townway representative (1A)	From Shuili, Nantou; specializes in medical management; entrepreneur in Zhushan for 16 years; 42 years old now.
	Townway staff (1B)	From Penghu; worked in Townway for 3 years.
	Beyoung Garden representative (1C)	Cousin of Ho; worked in Zhushan for 5 years.
	Tour Guide at Townway; bamboo artisan (1D)	Bamboo artisan in Zhushan; experience collaborating with designers for many years; worked in Zhushan for almost 40 years.
	Professor, in charge of industry–academia collaboration with YunTech (1E)	Digital media teacher at YunTech; main counselor for young entrepreneurs; 10-year collaboration.
	Student of specialty-based exchange accommodation (SBEA) stationed at Townway (1F)	Third-year master's student taught by Professor who stayed in the town for 6 months through SBEA program.
2. Yuantai	Yuantai representative (2A)	Third-generation Zhushan resident; entrepreneur in Zhushan for 9 years; family owned a factory; 38 years old now.
	Yuantai staff (2B)	From Nantou; young girl who had moved to the town 3 months prior.
3. KYOU	KYOU representative (3A)	Second-generation Zhushan resident; specializes in design; returned to Zhushan 10 years prior; created his brand 4 years prior; family owned a factory; 40 years old now.
	Representative of Pure Soap who cofounded Goods store with 3A and 4A (3B)	Son-in-law of Zhushan resident; specializes in design; entrepreneur in Zhushan for 5 years; full-time designer at a hospital.
	Representative of Forest Noodles collaborating with 3A (3C)	Second-generation noodle chef in Zhushan; specializes in design; entrepreneur in Zhushan for 6 years; built a tourist factory with a loan.
4. La-boos	Representative of La-boos (4A)	Second-generation Zhushan resident; specializes in business management; entrepreneur in Zhushan for 6 years; family owned a factory; 37 years old now.
	Collaborator of 4A for AxMon Art (4B)	Daughter-in-law of Zhushan resident; specializes in design; entrepreneur in Zhushan for 5 years.
5. Bamboo-Lai	Representative of Bamboo-Lai (5A)	Second-generation Zhushan resident; specializes in catering management; entrepreneur in Zhushan for 5 years; family owned a factory; 42 years old now.
	Father of Bamboo-Lai representative (5B)	First-generation Zhushan resident; bamboo craft teacher at National Chushan Senior High School; tutored bamboo crafts overseas for many years; worked in Zhushan for over 50 years.

3.3. Analysis and Organization of Research Data: Grounded Theory and Document Analysis

Coding is the basis of data analysis in grounded theory. The organization and refinement of data during the coding process allows for key categories to be identified. Some concepts related to a category serve as subcategories. By using the KJ method, the core category can be identified from the main categories [57]. The founder of KJ method is Tokyo humanist Jiro Kawakita, KJ is his English abbreviation. KJ method is to collect different data and classify them according to the relationship between them [58]. In this study, the field notes and interviews were formatted into verbatim transcripts, numbered, and decoded to organize the textual materials. The subcategories were then identified, and the KJ method was used to determine the main categories and construct chapters. New problems and issues that emerged during the collection and analysis of the data were revised or supplemented and analyzed in depth through a literature review and the field notes.

The process from data decoding to category construction for Townway was as follows: (1) numbering the field notes: the notes were numbered by time of observation and event using abbreviated keywords. For example, 20170507 represents the date of a local forum on shaping the features of a town of tea and bamboo ("tea and bamboo" was abbreviated as "TB"). The subtopics of major events were noted in each paragraph. The host's opening remarks and the guests' speeches were subtopics of the forum and were numbered in ascending order (01, 02, 03, and so on). Each paragraph was then open coded in ascending numerical order (−1, −2, −3, and so on); (2) numbering the verbatim transcripts: the transcriptions of the interviews were organized using a system of four alphanumeric codes. The first code represented the brands, which were numbered 1, 2, 3, and so on. The second code represented the interviewees, who were designated as A, B, C, and so on. The third code represented the order in which events were mentioned during the interviews: 01, 02, 03, and so on. The fourth code was the open code for an event, designated as −1, −2, −3, and so on; (3) grounded theory was used to integrate the open codes into a textual description of specific behaviors followed by classification of the subcategories. The subcategories were grouped into the main categories using the KJ method and used as the chapters for the analysis of the results; (4) finally, the conclusion was developed through a theoretical evaluation and dialogue with the interviewees.

This study reviewed articles, academic journals, dissertations, newspapers, magazines, and online data on issues related to Zhushan Bamboo Craft, Sky Yard guesthouse, Townway, social innovation design, and sustainability. A total of 86 books, 320 journal articles, 87 dissertations, and 163 media reports were reviewed. Section 2 presents the literature review, from which the following four dimensions of social innovation design evaluation were extracted: (1) analyzing social needs and using social capital [20,27,28,30–32]; (2) encouraging diversified participation and proposing solutions [17,18,21,23,24,37]; (3) generating group motivation and forming new connections [25,26,33,34,38–40]; (4) solving social problems and achieving sustainability [48,49,51,53–55]. The following three dimensions of sustainability were obtained identified from the literature review and the 17 sustainable development goals proposed by the United Nations: (1) economic sustainability [42–44,50]; (2) social sustainability [42–45]; (3) environmental sustainability [42–45]. A total of seven theoretical aspects (Figure 1) were used to evaluate the five brands investigated in this study, and their performance in terms of social innovation design and sustainability was comprehensively analyzed.

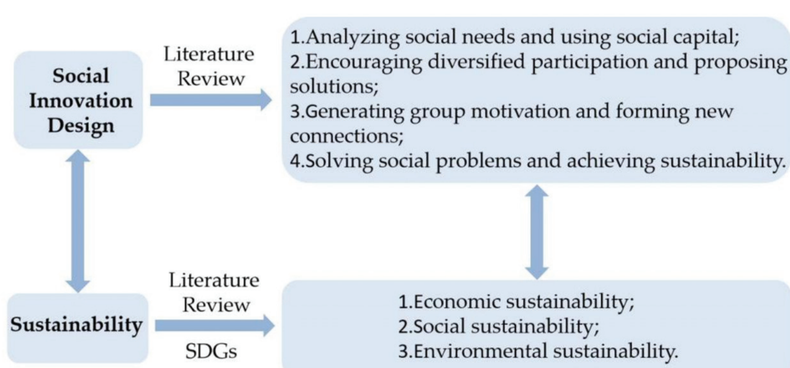

Figure 1. Social Innovation Design and Sustainability Theory Evaluation Orientation.

4. Analysis and Results

The young entrepreneurs of the bamboo craft brands in Zhushan launched innovative movements centered around bamboo. Among the brands, Townway is an agent of resource-integrated social innovation, and Yuantai is a model for industrial innovation. The others, namely, KYOU, La-boos, and Bamboo-Lai, are microentrepreneurial brands. Before the young entrepreneurs started their businesses in Zhushan, they had gained professional experience in management, design, and manufacturing. Four of the young entrepreneurs are locals of Zhushan, and their families once owned bamboo factories.

4.1. Townway

From the founding of the Sky Yard guesthouse in 2005 to the creation of Townway, this company has been in Zhushan for 16 years. The founder is a key figure in the young entrepreneur community, he preserves local culture and history and solves social problems. He has continued to introduce external resources to Zhushan while exporting its practice of sustainable development [59].The development process can be divided into three periods: (1) renovating a three-section residential compound (Sanhe Yuan) into the Sky Yard guesthouse: linking community resources on and off the mountains and attracting tourists (2005–present); (2) the founding of Townway and the process of becoming an intermediary in dialogue between locals and outsiders to cocreate value for the common good (2010–present); (3) shaping the Spotlight Gathering Settlement at Taisi Bus Station, incubating the Town's ecological mechanism to maturity, and the revitalization and marketing of Zhushan by young entrepreneurs in preparation for the Asia Revitalization Platform (2015–present).

4.1.1. Renovating a Three-Section Residential Compound (Sanhe Yuan) into the Sky Yard Guesthouse

1. Changing the negative perceptions of rural areas: using the natural and cultural features of the mountains as selling points for the guesthouse

In 2004, the founder began to sense a decline in culture and developed an idea of preserving culture through a guesthouse. After many challenges, in 2005, he completed the restoration of a century-old Sanhe Yuan and maintained its original appearance [60].

2. Changing the negative perceptions of the old mansion: conveying the cultural and historical value of a century-old house to visitors the text continues here

After the guesthouse space was built, they drafted informative texts, marketing copy, and self-recommendation letters to various departments of the government. They, then, created a website and promoted the guesthouse through a bulletin board system. Whenever tourists stayed in the B&B, the founder would project a film in the courtyard in the evening. The film was a documentary that explained the process of restoring the guesthouse and his concept of cultural preservation and entrepreneurial management. A major turning point occurred in December 2005, when the Nantou County Government invited internationally renowned musician to stay in the guesthouse and compose the eponymous album "Sky Yard", for which he received a Golden Melody Award [61]. This led to consistent coverage by TV channels and magazines, and the number of visitors rapidly increased. The founder was also invited to give speeches. During this time, he documented daily events on Facebook to convey his thoughts on cultural preservation and local development.

3. Reversing the tourism model for famous scenic spots: promoting Da-an community resources through tourism

From 2006 to 2009, the company developed the Da-an community by turning an unused tea factory into a restaurant, restoring the Da-an Historic Trail, and "*thinking about business from the perspective of the common good*" (1A02-3). They created tour itineraries with activities entitled "Reading on the Mountain, Dining in the Sky" and "Leisurely Paced Experience Tour with Lunchboxes," which not only enriched the travel experience for tourists, but also provided resources and improved the environment for the community, thereby working together with residents to create a local value.

4. Reversing the village tourism paradigm: turning tourists into social observers that contribute to cultural value

The founder stated that with such policies in place, "*the place loses its characteristics; the economy is irrelevant to the locals, and local culture and education are ignored*" (1A04-1). Thus, they connected the guesthouse, tea gardens, and Tianti Scenic Area on Da-an Mountain to the traditional shops at the base of the mountain. They created a program in which travelers gained authentic experience visiting a puffed rice store, an iron maker, and a quilt shop in Zhushan. At the beginning of the "Leisurely Paced Experience Tour with Lunchboxes" activity, the participants watched a documentary about the history of the Da-an Historic Trail in a restaurant, and each participant received a lunchbox designed by college students. The lunchboxes were wrapped in a bamboo mat and camellia cloth hand sewn at an old quilt shop in the town. The meals in the lunchboxes were prepared with ingredients from the local market [61].

5. Reattaching tourist guesthouse to local products: supplies from local industry and the first-hand experience of local charm

The household products in the guesthouse, such as the bed sheets, utensils, lighting, and snacks, were locally produced, and every aspect of the accommodation told a story about the community. Travelers who wanted to purchase an item in the guesthouse after using it could scan a QR code for more information. Thus, the guesthouse became a vehicle for local culture and generated a diverse range of revenue streams while benefitting the local economy (1A01-2).

6. Reversing the business model of traditional stores at the base of the mountain: the manufacturing process as a service model for tourism

The old stores in Zhushan retain traces of the traditional Taiwanese lifestyle. The linking of the local companies, stores, and the community encouraged the stores to change their service model to allow tourists to visit and learn and increased sales by 20–30%. For example, the owner of a puffed rice store strengthened his dedication and confidence in the industry by presenting his products and manufacturing process to tourists: "*tourism brings a steady flow of visitors and income to my store and renews my confidence in the production process*" [62].

4.1.2. The Founding of Townway

1. Turning untapped resources into opportunities: cooperating with local designers through specialty-based exchange accommodation

By the time the operations of the guesthouse had stabilized, Zhushan was still experiencing economic problems and youth drain. To solve these problems, they founded Townway in 2010 to connect local businesses, arts and culture, and ecology while attracting external resources. Townway rented an inexpensive vacant house and turned it into a youth hostel for the specialty-based exchange accommodation (SBEA) program. The town developed by exchanging local characteristics for external creative talent and drawing resources from society: "*sometimes, in certain months, there are more than 30 people here at once. They're asked to write a travel log and discover a new story every day*" (1B10-3).

In less than 2 years, more than 600 students went to Zhushan for SBEA and assisted local businesses in developing products, shooting short films, and improving the environment, and demonstrating the beauty of the tea gardens amid the bamboo forests and the diligence of Zhushan locals.

2. The public sector's focus on the common good: the cocreation of an online platform and products by locals and society

Townway has received subsidies from several public sector programs. For the Small Business Innovation Research program of the Ministry of Economic Affairs in 2011, Townway created an online platform for sharing information on stores, travel itineraries, and narrators. The platform also featured collaborative itinerary and cultural and creative product design. On the platform, locals co-worked with society to create demand, which drew participants and strengthened the competences of the companies and the town. After the online platform was established, the number of tourists increased; tour guides proposed itineraries, designers received projects, and companies could request product customization. The township office also recruited volunteers through the platform [63].

3. Drawing labor, funds, and ideas from universities and cooperating with local stores and organizations to shape local products and services

Since 2011, The founder has given hundreds of lectures annually at universities and participated in an industry–academia cooperation that allowed students to help transform the town with their expertise. For example, students cooperated with the Lai Far Blacksmith Shop, which originally manufactured agricultural tools, to make couple rings and assisted the Chiming Mifu store in developing new brown sugar and spicy flavors for the shop's products [64].

In 2012, Townway and mothers in the community established the Bamboo Life Cultural Association to promote the bamboo craftsmanship of Zhushan. In 2013, woven bamboo QR codes for use as local merchant signboards were developed with the support of the Smart Life Integration Talent Program of Nankai University of Technology (NANKUT). The participants from NANKUT proposed the idea of combining bamboo weaving with digital technology. Participants from Southern Taiwan University of Science and Technology used plastic panels to protect materials; final improvements were conducted by students from the National Cheng Kung University. Members of the association were responsible for producing all the materials and the woven bamboo [60].

4. The creation of the Bamboo Nest Class, a space for co-learning, and the Local Forum, an opportunity to exchange knowledge of local operations, revitalize the community, and reaffirm local identity

Zhushan required dialogue with schools, youths, residents, and enterprises. In 2012, through an industry–academia collaboration, Townway and YunTech completed the construction of the Bamboo Nest Class, a space for co-learning. In 2012, the venue for the Miaokou TED Talk event was changed to the Bamboo Nest Class, and the lectures became the Local Forum, a free event with no speaking fee. The event was regularly held from 7:00 p.m. to 10:00 p.m. on the last Friday of each month. At the event, entrepreneurs in Zhushan presented their plans, and issues, products, services, and local connections in Zhushan were discussed [61]. The event was also open to participants from outside Zhushan. Participants from various fields came together to communicate and share their practical experience and knowledge. The event encouraged youths to care about their hometown and created a sense of identity among the public (1A08-2).

5. Bringing local visibility and economy to Zhushan: strengthening the connection among homecoming youths and creating a structure of mutual support

From 2011 to 2014, SBEA, cultural creativity, and groups of local young entrepreneurs began to flourish in Zhushan. For example, one girl who had returned to her hometown to open a beef noodle shop remarked, "*because of our involvement with Townway, the shop has gained exposure, and its performance has improved*". Another girl who operated a dessert shop stated, "*Townway allows young entrepreneurs such as us, who have returned to their hometown, to support one another and connect, and it shows people our devotion and sincerity*" [62].

4.1.3. Shaping the Spotlight Gathering Settlement at Taisi Bus Station

1. Revitalization of the second floor of the bus station into Beyoung Garden and the use of local characteristics to create an aesthetic for the bamboo dining space

The Taisi Bus Station in Zhushan had long been unsanitary, with betel nuts and cigarette butts strewn everywhere by the roaming taxi drivers. In 2015, Townway rented the second floor of the Taisi Bus Station and transformed the long-unused staff dormitory into Beyoung Garden (Figure 2), which was completed in early 2016. The space was designed using the random method of bamboo weaving. The project staff remarked that Su used to make woven bamboo products: "*this is the first time she integrated bamboo weaving into a space. Participating in the production process opened her up to a new direction: creating a bamboo space*" (1B17-5). The manager of Beyoung Garden explained that visitors could sample multicourse meals created with various bamboo products. The famous sweet potatoes, bananas, and pineapples of Zhushan were also used to make the snacks and drinks: "*old stores that have been around for more than 40 years, such as the Chiming Mifu store and the puffed rice shop, created special milk tea and Da-an Mountain coffee*" (1C03-2). In addition to Beyoung Garden's function as a restaurant, the space held occasional exhibitions (Figure 3) and public events for local entrepreneurs.

Figure 2. Beyoung Garden.

Figure 3. Exhibition space.

2. The transformation of the Local Forum into the Spotlight Meetup activity, the steady growth of local and social capital, and the internal convergence of Zhushan's entrepreneurial power

Many start-up brands began to emerge in Zhushan in 2015. In response, the Local Forum was reorganized into the Spotlight Meetup activity, but the venue remained the Bamboo Nest Class. Young entrepreneurs used the platform to discuss their needs and experiences, and Townway proposed ideas for the following month. Participants included college teachers, students, and residents of Zhushan as well as residents from other counties and cities who were interested in Zhushan. Together, the group formed a community based on continuous learning rooted in entrepreneurship in Zhushan.

3. Townway designs tours and connects young entrepreneurs with local companies through a mutually beneficial relationship

The tours developed by Townway consisted of five parts which visitors could select to suit their needs. In the first part, the tourists visited Beyoung Garden and the youth exchange accommodation, painted walls and the headquarters of local entrepreneurs, and listened to Townway staff share their ideas at the Bamboo Nest Class. In the second part, the tourists listened to a young founder of a company in Zhushan discuss his entrepreneurial process and experience with bamboo craftsmanship. In the third part, the tourists sampled foods created with local ingredients at Beyoung Garden. In the fourth part, the tourists observed the manufacturing processes of the products sold in old shops and visited factories. In the fifth part, the tourists enjoyed the scenery of the Da-an Mountain and the century-old Sanhe Yuan at the Sky Yard guesthouse (1B18-6).

4. Expanding young entrepreneurs' knowledge, vision, and marketing channels through the support of the University Social Responsibility program and regional public sector revitalization projects and accelerating the revitalization of Zhushan.

From 2017 to 2019, youth-led brands in Zhushan were upgraded through the Design Flip Local Creation program of Nantou County and the National Development Council hosted by YunTech, which resulted in the creation of Tea and Bamboo: the Spotlight Settlement ecological mechanism. They have held several workshops and courses, organized forums and exhibitions, gathered forces from various social sectors, cultivated youth-led brands in Zhushan, and promoted local industry and culture. The project was supported through its long-standing partnership with YunTech as well as through projects at Tunghai University, National Chung Cheng University, and NANKUT. The University Social Responsibility program of the Ministry of Education prompted colleges and the community to collaborate and implement social innovations.

The first era of regional revitalization in Taiwan began in 2019. The Regional Revitalization Festival, supported by the Ministry of Economic Affairs and the Corporate Synergy Development Center, was held at the Taisi Bus Station in Zhushan (Figure 4). Projects related to the town were combined with local values and technology through events with three different themes, namely the art of food, the skill of craft, and the joy of living, to integrate multiple fields.

Figure 4. The Regional Revitalization Festival at Taisi Bus Station.

5. Revitalization of the first floor of the Taisi Bus Station as Taisi Ice Room: a public art space designed to attract locals and tourists

In August 2018, the first floor of the Taisi Bus Station was redesigned as a public art space (Figure 5). Local independent farmers, new residents, and senior citizens held fairs in the space, and local artists were invited to perform and exhibit their work, which attracted the locals as well as tourists. At the end of 2018, Townway established the Taisi Ice Room, an ice cream shop using local ingredients and bamboo utensils. Fruit farmers and local merchants in Zhushan collaborated to make the ice cream, and the flavors were inspired by southern France; Vietnamese coffee is used as the base of the ice cream, and it is paired with a small slice of French bread: "*Because there is a Vietnamese grocery store in front of the bus station, there are many new residents around*" (1A20-4).

Figure 5. The first floor of the Taisi Bus Station.

6. The Spotlight Gathering Settlement at Taisi Bus Station and the creation of an ecological mechanism: marketing Zhushan through local output

The Spotlight Settlement ecological mechanism was a means of encouraging homecoming youths to start their own businesses and bring innovation to the industries in Zhushan through their ideas and creativity. The partnerships were transformed into an incubation mechanism and a system for local development. Townway's duties include hosting local programs, exhibitions, experience-based tours, the Spotlight Meetup activity, and SBEA. First, a problem is identified through the Meetup; however, a problem can become an opportunity. Next, entrepreneurs discuss their needs and pose questions, and Townway matches the entrepreneurs with resources and talent listed on the digital platform and requests external resources. Then, the brands are upgraded through SBEA to become a new force after being marketed. Lastly, after the brands mature, their products are upgraded through a combination of the experience tour and SBEA, and the brands develop featured products. Townway matched young entrepreneurs by sharing spaces, markets, resources, and preorders. As for preordering products, Townway shared stories about the young entrepreneurs during the tours, and the visitors preordered gifts and made other purchases from the young entrepreneurs. Every year, six or seven youth-led brands were incubated: "*Regarding the resources, priority was given to these brands, and these brands should also correspond with the overall arrangement by Townway*" (1B02-4).

In 2017, Townway introduced the youth-led brands from Zhushan to the Huashan 1914 Creative Park and cooperated with Bright Ideas Co., Ltd. Because these brands were start-ups, their product output was slightly low: "*In this way, the overall output of the young entrepreneurs in Zhushan was condensed into a single force*"; this force represented Zhushan's bamboo culture. (2A22-5). Introducing the products from the rural community to urban cultural and creative spaces increased the visibility of the products and formed a channel for urbanites to access local culture. In 2020, Townway added two agencies, namely, Town Empowerment and Town Intelligence, to develop overseas cooperative projects with the intent of applying the experience of revitalizing Zhushan to other countries to solve issues in their development.

4.1.4. Evaluation Summary

The 17 characteristics of Townway explained in the three previous sections correspond to the seven theoretical dimensions of social innovation design and sustainability identified in the literature review. Its efforts are reflected in the following four aspects:

(1) The linking of local resources and the exchange of social capital. The guesthouse has revolutionized townships, possessing value in cultural heritage and revitalizing the local economy. In addition, local resources were directed toward utilizing unused

space and preserving the history of Zhushan to serve the public. SBEA was also used to enlist talent to support the local design efforts;

(2) The construction of public spaces such as the Bamboo Nest Class and the revitalization of the Taisi Bus Station provided a platform for local and social communication and resolved the lack of resources in the township;

(3) The close-knit collaboration between universities and the public sector provides a means for obtaining professional talent, knowledge, and funds. The collaboration also serves as an opportunity to implement social practice, which reinforces residents' confidence in local culture;

(4) The advocacy and implementation of social values. Social values are disseminated through the internet and other media to continuously implement innovative solutions, cultivate local youth-led brands, and attract like-minded individuals to engage in the cocreation process.

Because of the inherent limitations and difficulties associated with township-based entrepreneurship, certain areas were overlooked. This is reflected in the following:

(1) The limited number of business owners who benefit from matching. Because Townway is a free incubation cooperation brand that mainly focuses on providing opportunities for entities to obtain exposure and resources, some individuals or enterprises who were not included in the matching believe that they did not benefit;

(2) Less monitoring of ecological governance and sustainable development. The environmental sustainability component mainly involves the construction of bamboo crafts and the maintenance of the public space near Taisi Bus Station. Issues related to ecological governance and monitoring are seldom considered;

(3) The inefficient endogenous support system. Because the social capital mainly comes from universities and the public sector, only a small amount of business owners, youths, enterprises, and organizations in Zhushan work with Townway; the breadth of the local network is still relatively small. However, this is a common problem observed in the cultural industry and regional revitalization in Taiwan;

(4) Relatively low economic and environmental sustainability. Because the ratios of social values, social capital, and social activities are high, social sustainability is also high. By contrast, economic and environmental stability are relatively low. A more systematic business and circular economy should be established.

4.2. Yuantai

Yuantai is a bamboo factory with a history of 40 years with nine staff. It used to be mainly engaged in bamboo ear steak and bamboo stick needles. Due to maintenance difficulties, the third generation of bamboo artisan returned home to start a business at his mother's call in 2012. He worked in the army to repair aircraft engines for six years, where he received six months of design and drawing training. As he designed and sold T-shirts for four years (TB05-2), he was familiar with machinery, had a keen market observation, and had certain design abilities. With innovative actions, such as a road running event, bamboo products research and development, network marketing, and activity design, he closely linked brand value, life attitude, and market demand with the locals and society, and at the same time conveyed the sustainability of bamboo.

4.2.1. Continue Road Running Events to Drive the Formation of Sports Towns

1. Miaokou night running: the road running lasted for three years to form a sports atmosphere, addressing the lack of vitality in Zhushan

Facing the lack of social vitality in Zhushan for a long time, he thought he could hold road running events to let others know about different towns and villages. From the perspective of the local people, he thought that holding the activities at the temple entrance where people in villages and towns used to gather can best assemble crowds [60]. Those who love running in peacetime began to run on the road in groups, set up the club, Friends of Bamboo Slow Running, through Facebook social media, and called local residents to gather at the temple entrance every week for fun run activities. As a result, Zhushan transformed into a sports town because of its three-year continuous road running activities and its booming road running atmosphere.

2. Experience the local favor in road running: doing farm work on the road and combining large-scale activities with local food stores

He sometimes passed through the vegetable garden during his running. "*When he sees the elders he knows, he helps to perform farm work and obtains two bags of vegetables for rewards. This place, unlike cities, is full of human connections*" (2A01-3). Once, when runners passed through the farmland, a woman who tidied up the garden gave them some sweet potato leaves. After everyone took photos of this interesting life in running and posted them on Facebook, many people commented [60]. In the first large-scale road run, when the villagers heard that Zhushan was going to hold a big event, they were very much looking forward to it. They were initially asked for 30 rice crackers but gave 50, and the sweet potato shop also sponsored many honey sweet potatoes. Since 2012, he has hosted more than 300 road running activities for three consecutive years. With the support of the local government, social organizations, and the local residents, such activities have been combined with local businesses and cuisine to drive this depressed town with a continuous sports culture so that everyone has a sense of community identity and cohesion [60].

3. Use public sector resources in road running: use social resources to solve problems and advocate addressing ecological disputes

Yuantai planned a large-scale road run activity, "Love, Run into the Town", for the first time. The Zhushan Police Station, Zhushan Junior High School, Show Chwan Hospital, Township Office, neighborhood chiefs, and community volunteers provided a lot of manpower support in security maintenance, medical treatment, right of way management, and material supplies [61]. Furthermore, the Nantou County Government commissioned Yuantai to undertake the large-scale "Love, Starlight Fun Run" from Zhushan to Lugu. However, as the running route passed through a firefly habitat, it was opposed by the public. He and his team asked ecological experts to assess whether the route would affect the habitat and then publicized the assessment results of no influence to the public to calm them down [60].

4. Combine road running with local sightseeing: local tours and travel guides enhance popularity through advocating and online-sharing

In "Love, Starlight Fun Run", they arranged the road run at night and provided Zhushan's travel guide on the online registration page, which made passengers interested in staying longer and distributed their energy to different stores. After the activity, they deducted the required costs and donated part of the surplus to the ecological conservation unit [60].

5. Apply large-scale road running planning experience in other places: combine road running with the characteristics of aboriginal tribes and experience the enthusiasm of the aborigines

The practice of local development in which Zhushan participated attracted the attention of local villages and towns. Using the same way of localizing road running, Yuantai assisted the aborigines in Xinyi Township to carry out road running activities. The food and scenery were of outstanding aboriginal characteristics. Runners bring economic income to the tribe with their registration fees and fully feel the brightness and enthusiasm of the aborigines [60].

4.2.2. Practice Environmental Protection for Bamboo Life, and Make Full Use of Network and Social Value Marketing Products

1. Road running expands social capital and business opportunities: obtain the market demand for developing bamboo toothbrushes, conduct social activities, and deeply cultivate the industry at the same time

Yuantai entrepreneur stated, "Innovation in rural areas is easy to become a bright spot, and continuous activities become a kind of culture, which has gained market resources and interpersonal trust for self-entrepreneurship" (2A03-3). He met the guesthouse owner at the later stage of the road run, where he began developing bamboo toothbrushes because of guesthouse's demand for daily necessities (2A02-5). As everyone recognized the road running activity, the factory staff were willing to break through the technical problems with him and reduce the cost of product research and development and time test (2A02-6). He deemed it easier to face the problem and solve it faster in bamboo-producing areas. So long as he continues to conduct it without fear of difficulties, he believed he could perform it well (2A02-9).

2. Use test product prototypes in online media, bazaars, and in-person: gain experience and feedback to enhance product ease of use

Before the new product was officially launched, Yuantai conducted tests on the network platform many times, assessing the possibility of mass production according to consumer feedback (2A25-3). They also understood users' feelings after use through physical sales bases and enhanced the ease of use through continuous improvement in product materials, processes, and shapes (2A08-2). At the early stage of starting a business, they visited a large number of markets. They would also encounter matchmaking opportunities and gain experience and resources to increase the market share and on-site product experience. Starting a business in villages and towns is exchanged for mileage. "*Before developing products, we should first understand the source of everything, know all kinds of media and skills, find the combination of techniques matching modern from the traditional context, think from the user's point of view, and extend the development of products*" (2A16-5).

3. Research and development of conceptual products: advocate the social value of ecological environment protection, circular economy, Taiwan culture, and outdoor life through products

The brand value concept of Yuantai is based on environmental protection and sustainable circulation, and it is hoped that products can be decomposed in nature and can be produced and designed in a friendly way using local bamboo materials in Taiwan (2A02-3). In 2015, Yuantai developed the first bamboo toothbrush, created from Zhushan Mengzong bamboo, which was over four years old. It was free of bleaching and preservatives. The bamboo was sterilized by high-temperature cooking and then coated with a layer of non-toxic water-based paint for protection. No matter the product material or service, it has cultural value and is a sustainable concept. For example, the Yuanqi Concave Bean Cup is created out of bamboo waste. Through the proper use of bamboo, these waste materials are given new value without being discarded. The design of bamboo products focuses on social values, such as environmental education, outdoor style, Taiwan culture, and marine life. Together with designers, they have designed a series of thunder carving patterns, including the Taiwan Blue Magpie, Taiwan Black Bear, and Turtle (Figure 6).

Figure 6. Turtle-patterned bamboo cup.

In 2018, Yuantai invested in the flyingV fundraising platform with the project of Yuanqi Bamboo Straw—the Weakest Straw on the Earth—, of which the fundraising target was NTD 500,000. The fundraising plan clearly stated the return given to sponsors and donors. If the goal was achieved, Yuantai would start planting arrow bamboo seedlings [65].

4. Practice environmental protection personally: design products with one's own life experience and demonstrate the use of situations and social values

Most of the products developed by Yuantai's founder are based on his own life context. While living a natural, environmentally friendly life and outdoor camping (Figure 7), he brought the products into the situation to take photos and find more possibilities for using bamboo products in day-to-day life (2A13-5, 2A21-2). He often demonstrates the use of bamboo products through the internet and shares photos of product use—brand propaganda, showing a young, fashionable, environmentally friendly, and aesthetic quality life (2A04-2, 2A09-5). He believes that "*bamboo products are light, environmental protection, very suitable for outdoor activities. Bamboo forest is the best place for meditation, and life should be so beautiful*" [66].

Figure 7. Using bamboo products in bamboo forest.

The founder of Yuantai has been practicing a plastic-free life. After seeing the film of turtle suffering, the idea of developing bamboo straws arose. After starting his business, he met some friends with clean beaches and mountains, hoping to let everyone know how to implement seamless mountains and outdoors. "*The Marine Association volunteer group took him to pick up garbage, snorkeled while picking up garbage, and then met turtles*" (2A04-3).

5. Enhance the sense of participation in products and services: customization of goods and hand-made experience to enhance ties with users

Yuantai provides customers with customized services for products, such as laser personal slogans on bamboo toothbrushes, hand-painted patterns on bamboo cups, and customized services for joint funds of customers from the guesthouse and different enterprise groups (2B02-3). It cooperated with China Airlines to launch a bamboo toothbrush joint model, and high-end hotels, such as Satoyama-Jujo Hotel in Japan, also customized bamboo toothbrush products [67]. In order to convey a complete life concept by the brand, Yuantai arranged the physical shops in Zhushan into the space form of hand-made workshops in the second half of 2017, "*developing experience courses of bamboo toothbrushes and bamboo cups, so that consumers can experience the production of products*" (2A04-5).

6. Expand marketing channels with social issues: attract the active attention of mass media and social media, and expand marketing bases to Taiwan and even the world

The marketing channel of Yuantai is mainly the network and dozens of cooperative retail outlets, and most of them promote the brand through TV media interviews or industry speeches. In Yuantai's Facebook fan club, its official brand website, Pinkoi, and other network channels, and beautiful photos of bamboo products, are presented. The knowledge of environmental protection and outdoors is conveyed with strong Yuantai-style copywriting to share environmental protection information with consumers through the network, explain the design creativity of products in a Facebook online live broadcast, teach consumers how to maintain products, and let users better understand the characteristics of bamboo products (2A04-4). He stated, "*Agents from Germany and Japan see their products such as through FB. There are opportunities for cooperation*" (2A17-3). At the same time, after interviews with TV stations and online media, the order volume of products would increase rapidly (2B03-2). They market their brands through physical and virtual network channels, which have been stationed in Singapore, Japan, Malaysia, Europe, etc.

4.2.3. Actively Participate in the Activities Organized by Townway and Carry Out Cooperation between Young Entrepreneurs and Design of Local Activities

1. Actively participate in the Spotlight Meetup activity, link-shared resources, and gather local values

Yuantai has maintained close cooperation with Townway and has become a major local young entrepreneur brand. Group tourists and enterprises brought by Townway often visit the shops and factories of Yuantai and invite him to share his entrepreneurial experience and guide everyone in utilizing bamboo products. When starting a business in a township, the products of start-up brands are of little influence. However, many brand products come together, all coming from one place, forming a force. In turn, the place will be of high value and will be seen by everyone (2A03-2). These brands hatched in the Spotlight Settlement ecological mechanism cooperate without binding each other, growing fastest with each as an organism (2A13-7).

2. Design bamboo container for Taisi Ice Room and design Regional Revitalization Festival

Yuantai is responsible for the container design of the Taisi Ice Room ice cream. Bowls and cups are composed of bamboo materials rich in Zhushan. "*I hope tourists will come here to take away the culture of Zhushan, not a bowl of ice. Because bamboo is produced in Zhushan, and the things here are also related to bamboo products. There is no sense of disobedience*" (2A30-3). They were invited to attend the Kouba Factory Festival in Japan in October 2017, and were inspired to plan the Zhushan Craft Festival, hoping to connect local craftsmen in series (2A22-4). Therefore, Yuantai cooperated with Townway, mainly responsible for designing industrial activities, and held the Regional Revitalization Festival through multi-party cooperation.

4.2.4. Evaluation Summary

The 13 characteristics of the Yuantai correspond to the seven dimensions of social innovation design and sustainability identified in the literature review.

The Yuantai promotes events and aspects of industrial development that uphold social values. This is reflected in the following aspects:

(1) The running activities were organized to satisfy the needs of communities, and spreading awareness through the internet can increase the popularity of the brand;
(2) The implementation of a bamboo-based, environmentally friendly lifestyle and the use of the internet and social values to market products;
(3) Active participation in the organization and involvement in local design efforts.

Because the Yuantai is a young bamboo craft brand, its operations are limited by the following aspects:

(1) The small scale of the local industry. Most brands mainly focus on their own development;
(2) The relatively low level of industrialization. The brand mainly focuses on creating social ideal-based cultural and creative products. Few innovations and breakthroughs have been created through the combination of the bamboo materials and more sophisticated technology. The research and development for material technology requires more time and capital, which creates a challenge;

(3) The connection between the social values and social capital must be strengthened. Although the operations of the brand require a large amount of energy, social values must still be upheld; this requires collaboration with more enterprises, organizations, and research institutions.

4.3. Other Three Participating Bamboo Craft Young Entrepreneur Brands: KYOU, La-Boos, and Bamboo-Lai

Among the bamboo art young entrepreneur brands hatched by Townway, KYOU, La-boos, and Bamboo-Lai are busy with their own brand building on the one hand and co-operating with cooperative exhibitions, travel experiences, and local activities on the other. After returning home to start a business, they used their expertise and work experience to manage family factories, explore industrial operation modes, and focus on the innovation of product and service modes.

4.3.1. Use Professional Work Experience to Locate Entrepreneurial Brands Based on the Situation of Home Factories

1. Use experience in art design to improve bamboo production machines and learn traditional bamboo art

The head of KYOU is the second-generation descendant of the Bamboo Fan Bone Factory. He founded his own brand in 2017 and currently runs his home factory and brand together with his mother. He used what he had learned to redesign the original bamboo strips into bamboo products and held exhibitions of illustrations combined with crafts. He has worked in bamboo landscaping, graphic design, and product design for seven years. In 2010, he returned to Zhushan because his father was seriously ill and continued producing bamboo strips in his home. He knew many bamboo craftsmen, participated in the Bamboo Art Association of Nantou and Bamboo Art Society of NTCRI to learn traditional bamboo art techniques and joined exhibitions to improve the level of bamboo art creation and painting (3A03-5).

2. Use industrial management experience to rectify family factories and find the direction of brand entrepreneurship

La-boos is a bamboo factory with a 40-year history. It used to be a bamboo chopping board and has been in the bamboo factory in Fujian for more than 10 years. The second generation of bamboo artisan graduated from business management and later worked in many manufacturing companies. In 2012, he returned home to set up his own brand and develop environmentally friendly daily necessities, such as kitchen utensils composed of bamboo glulam. Meanwhile, the head of Bamboo-Lai returned home in June 2016 to start a business. He is the son of a senior bamboo artist in Zhushan. Remarkably, he has four years of hotel management, eight years of aviation, and two years of precision machinery work experience. Upon his return, he improved the spatial layout, machinery, and equipment of the family factory. Further, he used enterprise management strategies to enhance the brand management model, quickly thought about ways to make money, and first used sightseeing elements, DIY, and social networks to solve the crisis of capital income.

4.3.2. KYOU Develops Practical and Craft Bamboo Products, La-Boos Has a Stable Production Line of Bamboo Kitchen Utensils, and Bamboo-Lai Has Modular Bamboo Device Production

1. Research and development process and practical products of KYOU

Since 2011, the head of KYOU has cooperated with the Zhushan Township Office in the visual design of cultural activities for five years, attracting tourists to participate in activities with different themes. At the same time, he managed the production in the home factory, taught the courses of bamboo-weaving technology, and developed practical and technological products such as the combination of bamboo with different materials, illustration, and bamboo technology, forming personal characteristics. At present, there are bamboo products, such as bamboo certificate sets, bamboo postcards, bamboo clocks, bamboo storage devices, bamboo lamps, and bamboo key rings, among which the first two products are designed as experience courses (3A03-3).

2. La-boos takes bamboo kitchen utensils and environmental protection products as the core; the division of labor between Fujian and Taiwan factories is clear

The person in charge of La-boos, is familiar with bamboo materials and production processes. He cooperates with designers to jointly develop a variety of bamboo plates with healthy food-sharing concepts for children and adults, constantly upgrade and iterate the products, abide by the brand's core concept, and produce bamboo products with quality assurance for modern families. The business model of their products is stable, with affordable bamboo kitchenware, quality assurance, and a beautiful appearance as the core. The marketing channels include the brand's official website and Eslite, and other physical channels (4A03-4). In product chain management, Fujian factories mainly process rough embryos and semi-finished products of bamboo glulam to reduce costs and unify product quality, while Taiwan factories mainly process fine products and assemble finished products and design (4A04-2).

3. Bamboo-Lai combines the bamboo art experience course with sightseeing and adopts modular bamboo installation

The head of Bamboo-Lai returned to Zhushan and founded the International School of Bamboo Craft. He offered bamboo art experience courses, improved experience price and service quality, digitized experience cost, and hired students of bamboo art masters as teachers (5A01-2). In the business model, the travel agency was matched to form a bamboo craft tour itinerary. They mainly maintained brand management by making bamboo installations. At the same time, he created the bamboo plant project structured and modular and invited local residents with bamboo technology as production assistants to form a subcontracting mode of design and production to improve work efficiency and create job opportunities (5A08-3).

4.3.3. Young Entrepreneurs Met in a Spotlight Meetup Activity and Participated in the Incubation of Brand Mechanisms. The Concept of Resource Integration Affected Their Own Brand Development

1. KYOU cooperates with young entrepreneurs and mainly thinks about its own industrial business model

In 2015, the head of KYOU participated in the Spotlight Meetup activity organized by Townway and thought it could enhance the communication between people from different industries, share their respective problems and experiences, and bring motivation to their entrepreneurship (3A07-5). At the same time, he participated in the young entrepreneurs sharing and experience course of the Townway tour experience, held exhibitions, and entered the shop space together. In August 2017, KYOU, La-boos, and Pure Soap Handmade Soap Store jointly opened the GOODS physical store near Taisi Bus Station, which is the spatial information provided by Townway. In terms of the mode of operation, KYOU is still in the exploratory stage because while rural resources are scarce, few suitable manufacturers are mainly solved through network and product redesign. In brand marketing, most of them are now either undertaking government projects or offering various experience courses for promotion, and products are sold on the Pinkoi platform to position test products in the market (3A15-3).

2. The entrepreneurial concepts of La-boos and Bamboo-Lai are affected, but they need to have the ability to introduce social capital continuously

In 2016, the head of La-boos participated in the Spotlight Meetup activity and fully agreed with the role of Townway as an intermediary series platform. He thought that different micro-entrepreneurial brands had a symbiotic relationship and would have conflicts of interest, while Townway has a neutral role, which could represent local micro-entrepreneurial brands in publicizing them to the international community (4A07-13).

He participated in the activity many times, reached the qualification of incubation and upgrading, obtained cooperation resources, participated in the exhibition with young entrepreneurs, and put forward the plan of SBEA.

The founder of Bamboo-Lai also participated in the activities of Townway many times and joined in exhibitions, young entrepreneurs sharing, and the bamboo art experience. As they prepared for their bamboo craft experience courses, Townway interns and project personnel helped test design the course and evaluate its parameters and costs (5A11-5).

4.3.4. Evaluation Summary

The seven characteristics of the three youth-led bamboo craft brands, namely, KYOU, La-boos, and Bamboo-Lai, correspond to the seven dimensions of social innovation design and sustainability identified in the literature review. KYOU has focused on the development of bamboo craft products that are both practical and hand-made in small batches by mothers in the community. La-boos manufactures a line of a sustainable, environmentally friendly bamboo kitchen products, with a clear division of labor between the Fujian plant and the Taiwan plant. Bamboo-Lai has adopted a modularized system to manufacture their bamboo products. In terms of social capital utilization, it has mainly cooperated with Townway according to Townway's exhibitions and experiential journeys, which means that the former's level of proactive creativity is low. However, Bamboo-Lai's model is consistent with that of Townway, which prevents segregation. This also necessitates the continuous import of social capital.

5. Conclusions

5.1. The Three Elements: Analyzing Social Problems, Advocacy of Social Values, Proposing Innovative Solutions

In past industrial models in Zhushan Township, merchants and enterprises focused on their own operations and did not engage in dialogues or cooperation. The township also lacked connection between the local industry and social resources.

The five youth-led bamboo craft brands have upheld their values and maintained sustainability by analyzing social problems, proposing a series of innovative solutions, and realizing social innovation and sustainable development in Zhushan's bamboo craft industry. Their efforts are reflected in three aspects: (1) analyzing social problems; (2) advocacy of social values; (3) proposing innovative solutions. These brands are marketed through the following: (1) collaborations between universities and the public sector, such as the Bamboo Nest Class, Beyoung Garden, Taisi Ice Room, and the revitalization of the Taisi Bus Station; (2) the Spotlight Meetup activity; (3) the shaping of the Zhushan Spotlight Settlement ecological mechanism.

The construction of multipurpose public spaces is key to the social innovation and sustainable development of the Zhushan Township. These spaces can promote dialogues and exchanges, help groups reach a consensus, integrate the resources of multiple external parties, transmit information through various media, and match resources. To sum up, the resource-integrated Townway mainly carries out organizational innovation, industrial innovation, and social value advocacy and practice, of which its social capital mainly comes from the public sector and universities. Furthermore, the sustainable system of enterprises needs to be completed. The other four bamboo craft young entrepreneur brands focus on industrial innovation and participate in social activities. Their industrial chain and brand management mode, being constantly adjusted, remains unclear. In the early stage of Yuantai road running activities and bamboo environmental protection product development, social value drives the implementation of activities and products. Meanwhile, in the later stage, social issues are less involved, and in-depth scientific and technological research and development for bamboo material technology needs to be strengthened.

5.2. The Three-Stage Model of Zhushan Township: The Internal Collaboration and Enhancement; The Revitalization; The Marketing

The social innovations and sustainable mode created by the five youth-led bamboo craft brands can be divided into the following three stages (Figure 8):

(1) The internal collaboration and enhancement of Zhushan Township. Townway reached a consensus through dialogues and exchanged spaces with the Bamboo Nest Class and the Spotlight Meetup activity to cultivate the youth-led bamboo craft brands Yuantai, KYOU, La-boos, Bamboo-Lai, and other youth-led brands; these brands form the Zhushan Spotlight Settlement incubation;

(2) The revitalization of Zhushan Township. The youth-led organizations created an ecological mechanism for the township by matching local projects, experiential journeys, and local activities initiated by universities, the public sector, and enterprises;

(3) Marketing Zhushan Township. This mechanism can serve as an example of an ecological system that others can learn from. Zhushan Township is marketed through courses cultivating youth-based entrepreneurship, Zhushan exhibitions, documentaries, and the Asia Revitalization Platform. This ecological system can affect the Taiwanese society and the rest of Asia.

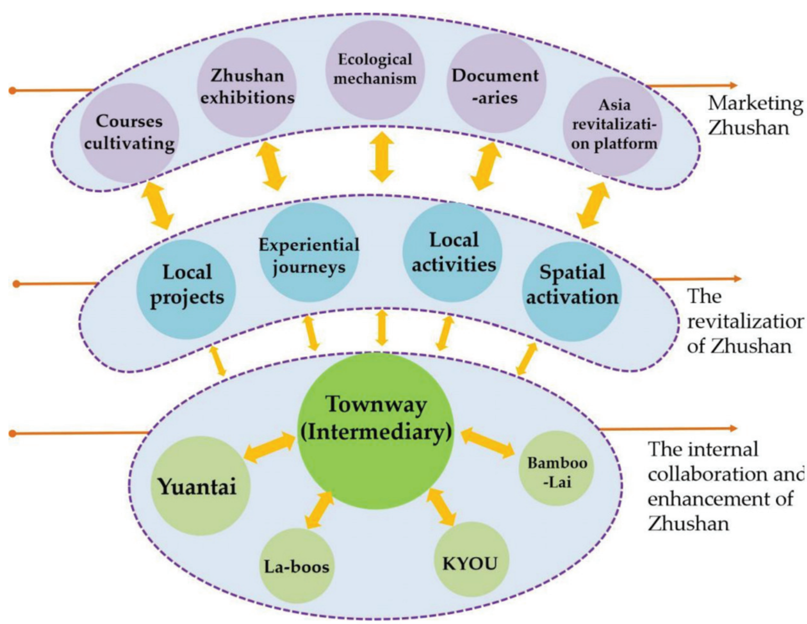

Figure 8. The social innovation design and sustainable mode of these brands.

The stakeholders of this model mainly include cooperative institutions or individuals. While the social influence and connection need to be further expanded, the sustainable development model of the economy and environment must also be enhanced.

5.3. Concerning Social Problems, Social Values, and Social Capital, Creative Solutions Can Be Put Forward through Multiple Participation and New Relevance So as to Practice Sustainable Values and Solve Social Problems

In terms of the development of social innovation design and sustainability, all five youth-led bamboo craft brands have gained social capital by targeting social problems and advocating social values; they used their social capital to solve social problems. In this process, the participation of local industries, enterprises, universities, the public sector, and nonprofit organizations is key to proposing creative solutions through joint deliberation.

These solutions represent a process of continuous experimentation and implementation; innovation plans are developed through implementation and correction. The participation of these groups can create new relationships, which can lead to the establishment of new organizations, space, and services. Local communities can generate a group dynamic to resolve social problems together. In addition, the participation of a diverse range of groups can promote economic, social, and environmental sustainability (Figure 9).

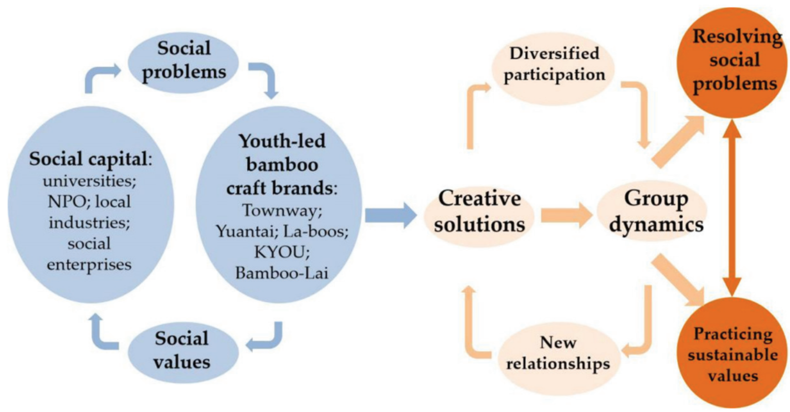

Figure 9. The relationship between social innovation design and sustainability of these brands.

Facing social problems in different periods, Townway integrated micro-social enterprises, constantly strengthened the core concept of locality and social value, encouraged multi-body participation through social capital, formed a new organizational platform, and achieved the sustainable development of the town. The other four micro-enterprises relied on the original family factory resources and network accumulation and used the network and modern marketing means to carry out industrial innovation in product and service models. In particular, Yuantai promoted product demand by practicing social value, which not only enhances local vitality but also achieves the environmental protection life value.

This paper analyzed five young bamboo craft entrepreneur start-up brands that are active in Taiwan's bamboo industry. Townway has been operating for more than 10 years before gradually forming a model of social innovation and sustainable development, which requires long-term efforts. Moreover, the other four micro-enterprises boast social capital accumulation in the early stage of family factories, whose founders have many years of urban work experience before returning home to start businesses. At present, this study only discussed five youth-led bamboo craft brands in Zhushan Township. In the future, a wider social innovation and sustainable development of Zhushan Township, as well as the different social innovation models between Zhushan and other towns in Taiwan, will be explored.

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Preliminary Research into the Sustainable Responsibility of Teaware Design—A Fs/QCA Analysis of the Influence of the Smell and Taste of Tea through Visual and Tactile Perception

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Abstract: Most studies concerned with sustainable design issues focus on product design to change user behavior, increase the product lifespan, reduce energy waste, or employ the user experience to influence the behavior of other users. Rarely do they discuss how to design products that meet the real needs of consumers and reduce design waste and excessive consumption. Teaware designers and producers have invisibly created a considerable carbon footprint with regard to nonrenewable clay and energy waste due to excessive production. Therefore, this research uses visual and tactile research into the Chinese drinking cup to integrate user experience and the designer's thinking and methods to ensure the sustainable value of the design and industry. This research uses experimental methods to collect and analyze the data with a fuzzy set qualitative comparative analysis (fs/QCA). The research found that the visual, tactile, and sensory perceptions of general consumers and tea professionals have different influencing factors on the taste system. This research provides evidence that the size of the tea-drinking container and the thickness of the cup's rim will affect the perception of the tea's taste and smell. This research provides new thinking for the design of Chinese tea-drinking utensils. It could solve social problems and dilemmas through design and contribute to the sustainable development of the design.

Keywords: visual perception; tactile perception; sustainability; sustainable behavior; design thinking; tea culture; fuzzy set qualitative comparative analysis; sustainable design

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1. Introduction

1.1. Background Information

Various cups have been developed for the world's three major non-alcoholic beverages, i.e., tea, coffee, and cocoa, with different heat-resistant materials and shapes due to the different brewing methods and cultures. Because the coffee brewing method is a one-time process and the coffee cannot be flushed twice, coffee cups in Western countries are primarily larger capacity and have handles. Meanwhile, tea can be called the national drink of the Chinese; Chinese tea culture is part of people's daily lives. Over history, tea drinking has gradually changed and developed with the evolution of tea. However, no matter how the tea leaves or the method of making tea evolved, making a good cup of tea is still inseparable from "tea utensils" and "water". The "tea book" of the Ming Dynasty recorded that "tea nourishes in water, and water performs well through utensils, and it completes by fire." The four factors must meet each other, and the lack of one means that the tea is incomplete [1]. In other words, besides good water quality, tea utensils play essential roles in making good tea. Due to the complicated process of making Chinese tea, the tea can be brewed many times. Through the control of time and temperature, the content of tea can be released time by time, so the tea aroma and taste are presented differently at each brewing. Therefore, the teacups are mostly small and without handles.

According to data from the China Business Industry Research Institute and the China Tea Exchange Association, new tea-drinking styles have inspired young people's consumption habits and vigorously promoted the consumption of Chinese tea. In 2017, China was the largest tea-consuming country globally, accounting for more than 1/3 of the world's tea production [2]. Recently, a tea ceremony with tea making and tea utensils arrangement for tea table design has gradually become popular. In addition to the tea carrier's functioning, the tea utensils serve the function of social communication, aesthetic education, and additional value for tea flavor.

In terms of communication during the tea ceremony, the teacup is the leading tea utensil that directly comes into contact with guests. Therefore, the teacup can carry the tea liquid, promote the tea quality, and be the medium for delivering visual aesthetics. Functionally, teacups must be embodied through touch with the hands and touch with the lips to reflect the tea taste and the warmth of the teacups. Therefore, the visual and tactile design considerations of teacups are becoming more critical.

1.2. Motives and Goal

Kreifeldt [3], in a study of the tactile aesthetics of aesthetic design, proposed that the object should be designed to give people a pleasant experience through its appearance or image. The appearance and image of the object can evoke the appropriate imaginary tactile feeling through vision. In other words, people's visual image of an object evokes psychological feelings and stimulates the corresponding tactile feelings. While most research focuses on the multisensory taste perception of chemical sensory stimulation and the physical content of the food itself [4], the proverb "you are eating with your eyes" [5] shows another meaning of visual influence on food taste. Visual images evoke appropriate imaginary tactile sensations and affect the taste of food. Studies have found that in addition to the tactile characteristics of foods that impact the judgment of several flavors [6], the external tactile information of packaging materials or containers also impacts the flavor and taste of food and beverages [7–9]. Van Rompay et al. [10] found that the visual and tactile stimulation of food or beverage containers in restaurants or supermarkets is closely related to the deliciousness and charm of food [11].

Human sensory receptors receiving external stimuli do not operate independently but are compounded and engaged simultaneously. While we are eating food, the smell and taste of the food itself, as well as our eyes, ears, and skin, also help to form a "flavor system" [11]. Many studies have found that consumers' perceptions of red wine, soda drinks, juice, coffee, and hot cocoa, consumer behavior, and the shape and color of the container are highly correlated [9,12–15]. Spence et al. [16] stated that, although there is a large population of tea drinkers globally, few studies explore tea's visual and tactile perception. In particular, there is a lack of in-depth investigation and research into Chinese teacups. From the environmental perspective of consumers' collective behavior, empirical investigation of the appropriate teacups for Chinese tea is necessary given the lack of published research on this issue, especially because China's tea consumption ranks first globally and the tea-drinking population is prevalent. Recent studies have found that some consumers, tea merchants, and tea art teachers focus on the material selection and the firing method of ceramic teacups. Although designers also focus on visual form innovation, the lack of research on sensory perception and teacup visual image leaves the designers without a design reference [17]. Under the policy of "industry culturalization" and the development of tea culture, the ceramic industry has turned to the production of tea utensils, seeking changes and innovations in design to increase competitiveness, and constantly creating all kinds of tea utensils [18]. However, continuous innovative designs have raised production costs and caused energy waste issues that undermine ceramic tea utensils' durable and environmentally sustainable properties. Social and environmental problems, such as stimulating consumption, energy, and resource waste, have attracted many scholars [19,20]. Especially in recent years, Taiwanese ceramic teaware creators have been keen on time-consuming and energy-consuming wood-firing teaware. The impact of environmental damage from an ordinary wood-burning kiln that requires at least 3 tons of firewood and smoke generated for at least 3 days of burning should not be underestimated.

Moreover, currently, there are 600 wood-firing kilns in Taiwan alone. The accumulated high energy consumption and endless environmental pollution problems must be reconsidered. In recent years, ceramic artists have introduced environmentally friendly wood-burning technology and built environmentally friendly wood-burning kilns to avoid air pollution caused by smoke and dust [21,22]. However, it still needs to consume a lot of wood energy to pursue beauty and artistic value. In addition, pottery clay materials are not renewable and reusable, and the environmental problems of high fuel and resource consumption make the ceramic industry an economic sector with a large carbon footprint.

In the current post-consumption era of excessive consumption, the artistic and practical evaluation of product design is crucial to add value to the design and solve the potential social crisis. From the viewpoints of design thinking regarding practical aesthetics and sustainable development, the researcher believes that understanding the relationship between the cup shape and the tea taste can assist in the design of practical tea utensils. In addition to embodying the concept of Kreifeldt [3] in his aesthetic design, that product appearance design provides people with a pleasant feeling, it can also contribute to the development of the tea industry and promote sustainable development. Therefore, this study aims to find the relationship between the factors influencing users' preference and tea tasting cognition and provide a user-centered design reference for tea designers, creators, and manufacturers.

2. Literature Review

"Feeling refers to the immediate and physiological response of the sensory system when it receives an external stimulus" [23], while the sensation is the "primitive experience" of the senses. The accumulation of these "primitive experiences" is the basis for the human construction of knowledge. The sensation can be divided into three stages: the physiological response of nearby stimuli, neural transduction, and the psychological response of consciousness (Figure 1) [24].

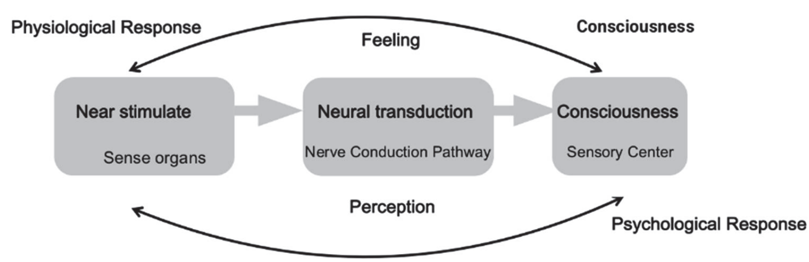

Figure 1. Three stages of the sensory process.

In this three-stage process, the sensation is completed by sensory organs, nerve conduction pathways, and the sensory center of the brain. Human eyes, ears, nose, tongue, and skin perform the senses of vision, hearing, smell, taste, and touch. From a physiological point of view, these sensory organs interpret as receptors, which are the entrance to the mental activity of information. The receptors convert the received stimulus energy into codes and then process these information codes into sensations with various properties and strengths that people experience. Vision is made possible by the visual system's external sensory organs to receive the stimulus of the optical energy of the external environment through the relevant parts of the brain's visual center to distinguish and see the subjective sensation of the impact [25]. The horizontal movement of the eyes is fast and comfortable, so it accounts for nearly 90% of the cognition of various sensations. Therefore, people distinguish things and rely mainly on optical transmission to obtain various types of information. People's first impression of contact with food is based on vision, so it plays a significant role in the sensory evaluation of food.

Sense of touch is a sensation for which the skin is responsible via the perception of pressure [26]. The skin is the sensor of touch and the largest sensory organ of the human body. The sensor of touch and pressure is the highest in the nose, lips, and fingertips. In the process of eating food, the touch of the mouth is still a significant experience [25]. Therefore, the object of this research is the teacup design, emphasizing the sensory experience generated in the mind after the lips touch the teacup.

Taste is a near sensation produced by direct contact between receptors and chemical stimuli. Common taste concepts include taste perceptions, such as sour, sweet, salty, bitter, and umami, and physiological stimuli triggered by different chemical substances. Eating occurs in the oral cavity, so taste activity is significant, but food taste does not depend on taste alone. Taste often interacts with other sensations [26]. "Perception refers to the process by which an individual selects, organizes, and explains the sentimental information through the brain's integration and cooperation based on the information collected by the sensory organs in response to the environmental stimuli" [26]. When we receive stimuli in our daily lives, the sensory organs transmit information to the brain and sensations. The brain begins to classify, understand, and interpret these sensations. When people's brains receive sensory stimuli, these repetitive sensory stimuli become experiences, and memories form a knowledge structure in the brain. Therefore, when the brain receives similar stimuli, these memories will be evoked in the cognitive structure of the brain. In this complex process, the five senses each have a division of labor and interact and influence each other.

Spence et al. [27] found that people's response to taste usually comes from the complex information processing of product experiences, such as smell, vision, taste, and touch, forming a sense of taste. In the complex integration of multisensory visual senses, the first senses reaching food produce pleasant expectations, transform and awaken other sensory perceptions, and enhance and obtain satisfying and pleasant memories and hedonic experiences. Extrinsic cues, such as the packaging and container, have exerted an influence on our perception of flavor. More empirical research is showing that the shape of product containers, also applied to drinking receptacles, demonstrates a strong association with consumer behavior and taste experience [13,15,28]. Studies have found that the shape of the glass had little effect on the perception of the aroma of wine when the subject could not see or touch the glass.

On the other hand, if the subject saw and held the glass, the shape of the glass had a considerable influence on the perception of the aroma and taste of the wine [29–31]. Delwiche and Pelchat [29] evaluated the aroma of four different glasses of wine in a blind test and found that the wine glass's shape had a subtle effect on the aroma. In addition, studies have found that even professional wine or tea tasters will still be affected by the shape of the glass, including their perception of taste and aroma [32,33]. Hummel et al. [34] studied whether wine glasses of the same height and caliber, but with different shapes, directly affect the aroma and taste of wine. The study found that two-thirds of the subjects believed they had consumed more than one type of wine, which means that one-third believed they had consumed one type of wine. Research has also found that the grade of wine is affected by the shape of the glass. In other words, the shape of the wine glass affects consumers' perception of wine aroma and taste. Compared to other drinking receptacles, the shape of the beverage (or wine) container has received more attention [10,35,36]. Cavazana et al. [9] studied the influence of the smell and taste of cola in different containers, and the results showed a multisensory interaction between the smell and taste of the beverage and the container type. Compared to cola in incompatible containers (such as water cups or plastic bottles), participants felt that cola in a typical cola cup was sweeter, stronger, and more pleasant.

Li et al. [37] used 1100 Chinese and 100 Americans as subjects to conduct a cross-cultural study on the influence of the visual appearance of the container on the subjective evaluation and taste expectations of tea. To subjects, they showed photos of Chinese and

British tea sets filled with green tea of Chinese and British brands. The subjects then discussed their feelings about each cup of tea and evaluated the taste expectations. The study found that the tea set affected the bitterness of the Chinese participants' expectations of their tea and the tea pleasure of the Chinese participants. This research showed that Chinese and British tea sets create different visual perceptions of tea due to the complex cognitive process. Through personal tea-drinking experience, emotions, and social and cultural interaction, these results further support the view that human perception is influenced by visual senses regarding the shape and material of the container, which significantly affects the consumer's drinking experience.

Another factor affecting taste is the sense of tactility between the human body and utensils, as human tactile receptors have the highest distribution density in the nose, lips, and fingertips [26]. The sensations that arise when these tactile sensations are in contact with the utensils, through the associative effect of the experience memory in the brain, produce psychological responses that affect the taste sense [26]. Bargh et al. [38] investigated the tactile experience in daily life, such as warmth, distance, hardness, and roughness. They explored the impact of the physical sensation of touch on psychological perception and the influence of cognition. The researchers found that the weight, surface characteristics, and hardness of materials felt by different tactile senses affect people's psychological feelings and even change people's thinking and decision making. Schifferstein [39] researched whether the tactile characteristics of containers affect consumers' judgments of beverage products. Participants were asked to evaluate the experience of drinking hot Earl Grey or iced lemon soft drinks in cups made of different materials such as glass, ceramic, opaque plastic, partially translucent plastic, and melamine. It was found that different cups significantly affected the judgment of sensory attributes such as "warm" and "sweetness." The tactile characteristics affect consumers' judgments of beverage products because of the differences in the color, weight, and texture of these cups made of different materials. Schifferstein found that the content material will affect the participant's experience of the drink content and that the participants preferred ceramic materials for the hot tea-drinking utensils.

The correspondence between the texture of the container surface and flavor has been proved. Van Rompay et al. [40] used a 3D printed surface pattern on the surface of the cup, which was an angular surface and a round surface. One hundred and sixty interviewees tested the bitterness and sweetness of sweet chocolate in the coffee cups with different surfaces. The cup with an angular surface produced a perception of the drink being more bitter and less sweet and seeming to have a more intense taste. In contrast, a cup with a round surface pattern elicited a sweeter taste evaluation and a less intense taste experience.

Tu et al. [8] applied the "sensation transference" theory proposed by Paras-Fiszman and Spence to study the influence of tactility on taste using packaging materials for traditional Chinese cold tea beverages. Blindfolded subjects tasted the same tea in glass, paper, and plastic cups with similar functions and sizes. The study found that the subject's touch of the container significantly affected their perception of the sweetness of the tea but did not affect the sourness or bitterness. At the same time, the test subjects felt that the tea in glass cups was colder than the tea in paper cups and plastic cups. Therefore, consumers' sense of touch has been shown to play a very important role in the stage of taste judgment.

Summing up the related research, the correspondence between the receptacle and taste attributes in Chinese tea remains essentially unknown. Hence, the present study was designed to investigate whether different shapes of teacups produce differences in perceptual evaluations (ratings of aroma and flavor attributes) of tea.

3. Methodology

3.1. Research Hypothesis

Based on the related literature discussion, to answer the research questions and achieve the research purpose, the research hypothesis is established to verify the relationship between the shape of the teacup and the tea test in a practical way. This research is divided into two parts: 1. The influence of the visual shape of the teacup on the taste and taste of tea. 2. The influence of the lip touch of the teacup on the taste and taste of tea.

The first part of the research explores the influence of the visual shape of the teacup on the tea taste. Li et al. [37] found that the difference in the visual shape of Chinese and western teacups and utensils subjectively affected the expectations of the tea taste. Other, related literature indicated that the visual style of the utensils impacts the taste perception of the drink [30,31], and the shape of the glass influences the aroma of wine [29]. Cavazana et al. [9] found that cola in a typical cola container feels sweeter and more robust than cola in a water or plastic cup. Therefore, this research proposes the following hypotheses:

Hypotheses 1 (H1). *The preference of the cup shape affects the taste and fragrance of the tea.*

Hypotheses 2 (H2). *The width difference of the teacup affects the taste and fragrance of the tea.*

Hypotheses 3 (H3). *The height difference of the teacup affects the taste and fragrance of the tea.*

The second part of this study is the touch influence of a teacup on taste and tea taste. The research found that the texture of the utensils with the touch of the skin has a significant impact on the sensory attributes "warm" and "sweetness" of hot Earl Grey tea or iced lemon drinks [14], and affects the bitterness of coffee and the sweetness of chocolate [40]. Tu et al. [8] took Chinese tea as a research object and found that utensils with different tactile effects affect tea's sweetness and cooling sensation. The touch sensation between the mouth and the teacup is the primary sensor of stimulation in this study. Therefore, this research proposes the following hypotheses:

Hypotheses 4 (H4). *The thickness of the teacup's rim affects the taste and fragrance of the tea.*

3.2. Experimental Design

In *The Practice of Social Research*, Babbie [41] mentioned that the experimental method is a mode of observation that enables researchers to explore causality and is particularly suited for research involving relatively limited concepts and propositions. The research hypothesis can be proved through the operation of various experimental designs. Because the experimental method focuses on determining causality, it is for explanatory rather than descriptive research purposes. Under the consideration of time-consuming operation, experiment site limitation, and the complicated evaluation standard between professional and general subjects, the quasi-experimental research method and no random sampling were adopted in this research. Nevertheless, the experiment is divided into two experimental and control groups. Because the purpose of the study is to explore whether there is a causal relationship between the shape of the cup and the taste and flavor of tea, the glazed teacup was used to avoid affecting the experimental results.

3.2.1. Experimental Materials

Generally, tea drinkers or consumers use personal experience to directly observe the tea color, smell the tea fragrance, and evaluate the taste of the tea. Their brewing methods and evaluation standards are different. Therefore, the Tea Industry Improvement Center of the Agricultural Committee of Taiwan invited experts to comment on and formulate tea taste as strong, umami, sweet, smooth, rich, mellow, plain, coarse but plain, coarse but astringent, immature but astringent, bitter, astringent, and watery tastes [42]. There are five basic tea tastes, namely, bitter, astringent, sweet, sour, and umami. Therefore, this study summarizes the taste reviews and descriptions of the tea tastes of the 12 comments above. Then we comprehensively sort out five groups of opposing taste and taste comments as follows: strong → watery; umami→ bitter and astringent; sweet → immature but astringent; sweet → coarse but astringent; and rich→ coarse but plain. This study uses the semantic difference method to make a semantic scale. Each group of taste and taste comments is divided into five levels of semantic space (see Table 1).

Table 1. Taste and aroma scale of tea.

Taste and Aroma of Tea		Scale Level					Taste and Aroma of Tea
		Very Much (5)	**A Little (4)**	**Normal (3)**	**A Little (2)**	**Very Much (1)**	
Taste	Strong	The taste is solid	The taste is a little strong	The taste is normal	The taste is a little light	The taste is very light	Watery
	Umami	The taste is solid with an umami taste	The taste is a little umami taste	The umami taste is normal	The taste is a bit strong, bitter, astringent	The taste is very strong, bitter, astringent	Bitter and astringent
	Sweet	The taste is delightful and refreshing	The taste is a little sweet and refreshing	The sweetness is normal	The taste is a bit grassy and astringent	The taste is very grassy and astringent	Immature but astringent
	Smooth	The taste is delightful and smooth	The taste is a little sweet and smooth	The smoothness is normal	The taste is a bit astringent and not smooth	The taste is very astringent and not smooth	Coarse but astringent
	Rich	The taste is delightful and rich	It tastes a bit sweet but not rich	The sweetness and richness are normal	The taste is a bit light and not rich	The taste is very light and not rich	Coarse but plain
Aroma	Fragrant	The aroma is very pure and not mixed	The scent is regular and pure but not high	Normal scent	A little bit mixed with the non-tea smell	Non-tea smell	Messy smell

In this study, high mountain tea grown at an altitude of over 1000 m was selected as the experimental material because the taste and aroma of the tea are the most prominent and easy to distinguish. Furthermore, according to the professionally accepted tea brewing method, 3 g of tea was immersed in a 150 cc white porcelain cup for 6 min with 100 °C water. The tea was used as the final material of the experiment.

3.2.2. Participants

While the tea taste classification is shown in Table 1, it is hard for the general consumer or public to distinguish between tea taste and fragrance. To achieve accuracy and effectiveness, this research experiment was divided into experimental and control groups, and there are 17 people for each group. The test subjects in the experimental group were professionally trained tea experts, tea art teachers, or tea producers. The control group consisted of amateurs who have not generally received training in tea art. The data from the two groups are included in the analysis (see Table 2).

Table 2. Participant demographics.

Experimental Group		**Control Group**	
Variable	**Percentage (N = 17)**	**Variable**	**Percentage (N = 17)**
Gender (N = 17)		Gender (N = 17)	
Male	29% (5)	Male	41% (7)
Female	71% (12)	Female	59% (10)
Age		Age	
35–44	24% (4)	15–24	12% (2)
45–54	47% (8)	25–34	29% (5)
55–64	35% (5)	55–64	59% (10)
Education		Education	
University	41% (7)	University	82% (14)
Post-Graduate	59% (10)	Postgraduate	18% (3)
Frequency		Frequency	
Every day	82% (15)	Every day	35% (6)
Sometimes	18% (2)	Sometimes	65% (11)

3.2.3. Experimental Products

The main object of this research is to explore the visual and tactile impact of the teacup shape on the taste of the tea. Therefore, the selection of the cup shape is based on the part of the teacup that comes into contact with the eyes and lips. The selection criteria were the visual shape height (deep abdomen and shallow abdomen), the caliber of the teacup (wide abdomen and narrow abdomen), and the thickness of the cup's rim. In this study, 5 teacups (A–E) were selected: (A) narrow abdomen (diameter width: 6.6 cm, height: 4 cm, thickness: 0.4 cm), (B) open narrow abdomen (diameter width: 6.7 cm, height: 3.5 cm, thickness: 0.3 cm), (C) constricted shallow belly (caliber width: 6.3 cm, height: 3.8 cm, thickness: 0.4 cm), (D) open deep belly (caliber width: 4.9 cm, height: 4.2 cm, thickness: 0.25 cm), and (E) open narrow shallow abdomen (caliber width: 5.4 cm, height: 2.6 cm, thickness: 0.2 cm), serially numbered as A–E (Figure 2). Because past studies have found that color is also one of the visual variables that affect taste, the five teacups were white porcelain cups.

(A) **(B)** **(C)** **(D)** **(E)**

Figure 2. Cups (**A**–**E**).

3.2.4. Questionnaire

According to Table 1, the questionnaire was classified into (a) the intensity of tea liquid, (b) the intensity of tea umami, (c) the intensity of tea sweetness, (d) the intensity of tea smoothness, (e) the intensity of tea richness, (f) the degree of tea aroma, and (g) the preference of teacup shape according to a 5-point Likert scale.

3.2.5. Environments

The professional standard tea environment is better with natural lighting. The light is sufficient and uniform, and not direct. If the lighting is insufficient, fluorescent lamps can be installed to supplement the light. In this study, fluorescent lamps were used in the room to make it easier for the subjects to observe the color of the tea. The interior was maintained at a temperature of about 22~24 degrees and was clean, without odor interference.

3.2.6. Design and Procedure

The study was conducted in February 2021. This study adopted non-random sampling; snowball sampling was used. The majority of the professional participants were recruited from among the members of tea-related associations. The amateur participants were recruited from the community and were interested in the study. All the participants were informed that they would be tasting and evaluating tea and were led into a quiet, well lit, air conditioned testing environment. The maximum number of subjects participating in this study was five at a time. A glass of water was prepared for the subjects before the test to avoid intentional residue in the oral cavity. The process of the experiment and the content of the questionnaire was explained in advance. The subjects were given 10 min to fill in the first part of the questionnaire and read the reference content of the questionnaire. The tea in the Section 3.2.1 experiment was brewed in 10 min, poured into the teacups in order, and placed in front of the test subject. The test subject drank the tea in the given cup in sequence. Then the subject filled in the questionnaire regarding the taste of the tea consumed and the preference regarding the cup shape.

3.3. Data Analysis

Fuzzy set/qualitative comparative analysis (fs/QCA) is used for this study. Because the causal asymmetry of variables in the study exists, the complex integration of multi-sensory and the exploratory findings are subject to causal equifinality or asymmetry [43]. Equifinality is the idea that "a system can reach the same final state from different initial conditions and by a variety of different paths" [44]. The most significant difference from other statistical research methods is that fs/QCA supports equifinality between variables. In other words, each specific result (for example, affecting the intensity of tea taste) may be caused by different combinations of elements. The complex and independent multidimensional nature of visual and tactile perception rests not on a single attribute, but instead on the relationships and complementarities between multiple characteristics. In contrast to the common correlational understanding of symmetric causality, fs/QCA provides an understanding of asymmetric causality. That is, the causes leading to the presence of the outcome may be quite different from those leading to the absence of the outcome.

Three steps are required to implement fs/QCA. First, the original data must be converted into fuzzy numbers, called data calibration. The fuzzy set between 0 and 1 is converted into a continuous variable called the degree of membership. Therefore, a membership score of 0.5 is a member of what is known as the intermediate set. To calibrate the research variables of this study, the direct method set the values 0.95, 0.50, and 0.05 as three thresholds to ensure that the original data was not affected by the bias of sample characteristics [45,46].

Secondly, two steps are needed to construct the truth table of Bollinger's logic, including setting the number-of-cases threshold and the consistency threshold. Finally, fs/QCA software can produce three types of output: parsimonious solution, intermediate solution, and complex solution. The complex solution presents a large and impractical number of combinations [47], therefore, Ragin [48] suggested that the intermediate solution is superior to the other two. The results of the truth table are rules and results that summarize the sufficiency of all possible combination subsets of causal conditions [49]. Consistency and coverage are essential indicators to check the condition combination of fs/QCA's explanatory power. Consistency is like a significant level in quantitative analysis, and its purpose is to evaluate the degree of causality between conditional combinations. The consistency must be greater than 0.75. Coverage is the degree of interpretation of the condition combination and represents whether the event condition combination has strong explanatory power. Calibration is also helpful for qualitative research in interpreting relevant and irrelevant variation, and quantitative research inaccurately places cases relative to each other [47]. In this study, the appearance design of the teacup with incomplete duality led to a cross-modal perception of the interaction of multisensory perceptions. However, traditional variance-based methods focus on variables' relation and effect in a model to measure the unique contribution of each variable to the overall observation data. Instead, fs/QCA focuses on the complex and asymmetric relationship between the complexity of outcome and causality. It intends to discern the complex solutions and combinations of independent variables. Another benefit of employing fs/QCA is without the limitation of sample size, ranging from very small (<50 cases) to very large [45]. Therefore, fs/QCA, as a bridge between qualitative and quantitative research, is an appropriate approach to establish a truth table of causal conditions for this small-/middle-number case study [48].

Because fs/QCA does not test for construct reliability and validity, before applying fs/QCA, the author used variance-based methods to examine the net effect between variables in a model. All independent variables were set as predictors of one dependent variable in PLS-SEM analysis. Using SmartPLS software to examine the models was significant (Figure 3, R^2 = 0.929, 0.940), indicating that the model of a cause-effect relation between tea taste and the shape of teacups is significant. In other words, the shapes of teacups are determinants of tea taste and fragrance. The explanation of sufficient or necessary conditions of the factors of teacup shape to the outcome would be identified by fs/QCA in the following section.

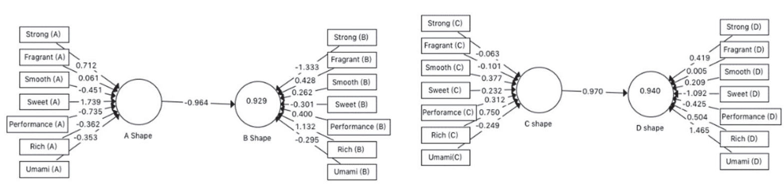

Figure 3. Finding from PLS-SEM analysis.

4. Results and Discussion

4.1. Descriptive Statistical Analysis

Tea taste data from the 34 subjects for both groups were analyzed. The case number is 17, and the missing number is 0 for both groups. The descriptive statistical analysis (Tables 3–10) found that the experimental and control groups had different responses to the vigorous-intensity of tea. The average number of D cups was the highest in the experimental group, and the average number of B cups was the highest in the control group. In the tea freshness and sweetness experiment, the experimental group had the highest average number of B cups, while the control group had the highest average number of A cups. In terms of tea smoothness, richness, and overall performance, the experimental group had the highest average number of D cups, and the control group had the highest average number of A cups. The tea fragrance experiment found that the experimental group and the control group had a consistent consensus. The average number of A cups was the highest, and the standard difference was between 0.5–0.8, which is not significant. In the experimental group of teacup preference, the average number of open deep abdomen cups was highest in D cups. The average number of B cups in the control group was the highest.

Table 3. Descriptive statistical analysis of strongness of tea.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	3 (2.941)	1.085 (0.998)	1 (1)	5 (5)
B	2.882 (3.471)	0.832 (0.915)	1 (1)	4 (5)
C	2.765 (3.176)	1.059 (0.922)	1 (1)	4 (5)
D	3.118 (3.411)	0.758 (0.974)	2 (1)	5 (5)
E	2.471 (3.352)	0.915 (0.967)	1 (2)	4 (5)

Table 4. Descriptive statistical analysis of umami of tea.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	3.412 (3.471)	0.844 (1.091)	2 (1)	5 (5)
B	3.647 (2.941)	0.588 (1.161)	3 (1)	5 (5)
C	3.412 (3.294)	0.600 (1.072)	2 (2)	4 (5)
D	3.353 (3.294)	0.904 (1.072)	2 (2)	5 (5)
E	3.235 (3.0589)	0.9412 (0.998)	2 (1)	5 (5)

Table 5. Descriptive statistical analysis of sweetness of tea.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	3.059 (3.529)	1.162 (1.091)	1 (1)	5 (5)
B	3.412 (3.235)	0.844 (1.165)	2 (1)	5 (5)
C	3.118 (3.235)	0.832 (1.165)	2 (1)	5 (5)
D	3.412 (3.352)	1.032 (1.026)	1 (2)	5 (5)
E	2.824 (3.059)	0.856 (0.998)	2 (1)	5 (5)

Table 6. Descriptive statistical analysis of smoothness of tea.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	2.941 (3.647)	1.056 (0.967)	1 (2)	5 (5)
B	3.058 (3.235)	0.872 (1.112)	2 (1)	5 (5)
C	3 (2.824)	0.907 (0.923)	2 (1)	5 (4)
D	3.118 (3.235)	0.900 (1.113)	2 (2)	4 (5)
E	3 (3.059)	0.907 (0.872)	2 (2)	5 (5)

Table 7. Descriptive statistical analysis of richness of tea.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	2.941 (3.529)	0.802 (0.848)	2 (2)	5 (5)
B	2.824 (3.294)	0.9843 (1.015)	1 (1)	4 (5)
C	2.529 (3.235)	0.9151 (1.059)	1 (1)	5 (5)
D	3.235 (3.118)	0.807 (0.900)	2 (1)	4 (5)
E	2.647 (3.353)	1.026 (0.836)	1 (2)	5 (5)

Table 8. Descriptive statistical analysis of fragrance of tea.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	3.88 (4)	0.471 (0.840)	3 (2)	5 (5)
B	3.529 (3.412)	0.848 (0.974)	2 (1)	5 (5)
C	3.412 (3.235)	0.771 (0.941)	2 (1)	5 (5)
D	3.353 (3.471)	0.836 (0.848)	2 (1)	5 (5)
E	3.412 (3.529)	0.771 (0.606)	2 (3)	5 (5)

Table 9. Descriptive statistical analysis of overall performance of tea.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	3.471 (3.706)	0.696 (0.892)	2 (2)	4 (5)
B	3.412 (3.471)	0.691 (1.091)	2 (2)	5 (5)
C	3.353 (3.353)	0.681 (0.967)	2 (2)	5 (5)
D	3.706 (3.529)	0.892 (1.036)	2 (2)	5 (5)
E	3.294 (3.352)	0.892 (0.9037)	2 (2)	5 (5)

Table 10. Descriptive statistical analysis of teacup preference.

Variable	Mean Exp/Ctrl	Std. DEV Exp/Ctrl	Minimum Exp/Ctrl	Minimum Exp/Ctrl
A	3.118 (3.471)	0.831 (0.696)	1 (3)	4 (5)
B	3.412 (3.647)	0.600 (0.836)	2 (2)	4 (5)
C	3.588 (3.471)	0.974 (0.848)	2 (2)	5 (5)
D	3.941 (3.176)	0.725 (0.922)	2 (2)	5 (5)
E	3.235 (3.059)	0.807 (0.937)	2 (1)	5 (5)

The standard deviation (Std. DEV) of each variable in Tables 3–10 shows the degree of disagreement among the subjects. The standard deviation is between 0.470 and 1.165, which means that the participants' tea taste perception and teacup preference were quite different from each other. Thus, the participant's tea preference perception was subjective. Through fs/QCA software, the researcher can find the causal relationship of the variables.

4.2. Fs/QCA Data Analysis

Dependent variables (y) are tea tastes classified into seven variables, y1 to y7. They are, separately, the strongness, umami, sweetness, smoothness, richness, fragrance, and overall tea performance. The independent variables (x1 to x4), the appearance of the cup, are defined as the teacup preference, the width of the teacup's diameter, the height of the teacup, and the thickness of the teacup's rim (shown in Table 11). Fs/QCA is used to analyze the causal relationship between the teacup's appearance and the preference with the taste perception of tea. The function formula is Y = F (X). The functions are summarized in Table 12.

The first step in fs/QCA analysis is to calibrate the dependent and independent variables into fuzzy or clear sets. The process followed to convert continuous variables into fuzzy sets is based on the method proposed by Ragin [45]. The direct method set the values 0.95, 0.50, and 0.05 as three thresholds [45]. Because this study used a 5-point Likert scale to measure the structure, they are calibrated as fuzzy sets. Therefore, the intersection point is set at 3. By performing two separate fs/QCA analyses, a truth table of 2^k rows was generated, where k represents the number of predictors and each row represents a possible combination (solution). The results of the fuzzy set analysis are summarized and shown in Tables 13 and 14.

Table 11. Definitions of variables.

Variables	Definitions
y	Tea test
y1	The strongness of tea
y2	The umami of tea
y3	The sweetness of tea
y4	The smoothness of tea
y5	The richness of tea
y6	The fragrance of tea
y7	The overall performance
x	The appearance of a teacup
x1	The preference for a teacup
x2	The width of the teacup's diameter (the caliber size of a teacup)
x3	The height of the teacup
x4	The thickness of the teacup's rim (the thickness of the cup at the mouth)

Table 12. Visual and tactile functions.

Function	Remarks
y1 = f (x1, x2, x3, x4)	The relationship between the **strongness** of the tea (result) and cup preference, cup diameter width, cup height, and rim thickness (condition)
y2 = f (x1, x2, x3, x4)	The relationship between the **umami** of the tea (result) and cup preference, cup diameter width, cup height, and rim thickness (condition)
y3 = f (x1, x2, x3, x4)	The relationship between the **sweetness** of the tea (result) and cup preference, cup diameter width, cup height, and rim thickness (condition)
y4 = f (x1, x2, x3, x4)	The relationship between the **smoothness** of the tea (result) and cup preference, cup diameter width, cup height, and rim thickness (condition)
y5 = f (x1, x2, x3, x4)	The relationship between the **richness** of the tea (result) and cup preference, cup diameter width, cup height, and rim thickness (condition)
y6 = f (x1, x2, x3, x4)	The relationship between the **fragrance** of the tea (result) and cup preference, cup diameter width, cup height, and rim thickness (condition)
y7 = f (x1, x2, x3, x4)	The relationship between the **overall performance** of the tea (result) and cup preference, cup diameter width, cup height, and rim thickness (condition)

The exact two causal relationship solutions were found for the seven causal relationship functions for the control group. According to the literature, there is a positive correlation between the perceived aroma intensity and the opening diameter of the wine glass [50]. Given the research that has been documented on coffee [51], one might expect that the physical properties of the cup may affect the perception of complex tastes and aromas in tea. The first solution is x2 * ~x3. When one is drinking tea, if the height of the cup is not considered, the diameter of the cup (that is, the size of the cup) influences the strongness, sweetness, smoothness, richness, fragrance, and overall performance of the teacup. The interpretation of this solution agrees with Hummel et al.'s [34] study, suggesting that the shape of a wine glass may affect the perceived bouquet and taste of the wine.

Table 13. Control group fs/QCA result.

Function	Causal Solution	Raw Coverage	Unique Coverage	Consistency
y1 = f (x1, x2, x3, x4)	x2 * ~x3	0.552	0.109	0.839
	x1 * x2 * x4	0.405	0.049	0.839
y2 = f (x1, x2, x3, x4)	x2 * ~x3	0.520	0.085	0.769
	x1* x2 * x4	0.415	0.065	0.838
y3 = f (x1, x2, x3, x4)	x2 * ~x3	0.516	0.095	0.787
	x1 * x2 * x4	0.399	0.060	0.832
y4 = f (x1, x2, x3, x4)	x2 * ~x3	0.538	0.095	0.791
	x1 * x2 * x4	0.400	0.065	0.842
y5 = f (x1, x2, x3, x4)	x2 * ~x3	0.538	0.090	0.829
	x1 * x2 * x4	0.422	0.059	0.887
y6 = f (x1, x2, x3, x4)	x2 * ~x3	0.500	0.086	0.846
	x1 * x2 * x4	0.400	0.063	0.923
y7 = f (x1, x2, x3, x4)	x2 * ~x3	0.509	0.091	0.845
	x1 * x2 * x4	0.402	0.064	0.909

Table 14. Experimental group fs/QCA result.

Function	Causal Solution	Raw Coverage	Unique Coverage	Consistency
y1 = f (x1, x2, x3, x4)		**No solution**		
y2 = f (x1, x2, x3, x4)	x2 * x4	0.454	0.073	0.895
	x2 * ~x3	0.567	0.016	0.913
y3 = f (x1, x2, x3, x4)	x2 * x4	0.456	0.070	0.806
	x2 * ~x3	0.568	0.013	0.823
y4 = f (x1, x2, x3, x4)	x2 * x4	0.462	0.063	0.764
	x2 * ~x3	0.570	0.010	0.773
y5 = f (x1, x2, x3, x4)		**No solution**		
y6 = f (x1, x2, x3, x4)	x2 * x4	0.461	0.099	0.948
	x2 * ~x3	0.523	0.012	0.880
y7 = f (x1, x2, x3, x4)	x2 * x4	0.455	0.082	0.910
	x2 * ~x3	0.538	0.011	0.880

The second solution is x1 * x2 * x4. When one is drinking tea, among all factors, the diameter of the cup, the thickness of the cup's rim, and the preference for the cup will affect the strongness, sweetness, smoothness, richness, fragrance, and overall performance of the tea.

The finding in this solution corresponded to Doorn et al.'s [52] cross-cultural research on the shape of coffee cups. Visual information, such as the size and height of the coffee cup, could affect the consumer's sensory expectation. The effect of preference for the cup found in this solution could be related to emotional responses to the stimuli. Spence and Gallace [53] mentioned that a consumer's emotional response elicited by a tactile aspect of the receptacle might influence the expectation of the drinking experience. The feeling regarding the experience of drinking mineral water has been related to the pleasantness of the container [39].

There were different combinations of causal relationships among the seven functions of tea taste perception for the experimental group. In the experimental group, the teacup's appearance and preference had no causal relationship to the strongness and richness of the tea taste because the consistency is lower than 0.75. The others had two sets of the same causal relationship combinations. The first solution x2 * ~x3 is similar to the first one of the control group. It was found that for professionals, without considering the height of the cup, the caliber size of the teacup had a significant impact on the umami, sweetness, smoothness, fragrance, and overall performance of the tea but not on the strongness and richness of the tea taste. It can be explained that the width of the diameter of the cup is a sufficient condition for affecting the umami, sweetness, smoothness, fragrance, and overall performance of the taste.

The second solution is x2 * x4. When one is drinking tea, among all factors, the diameter of the cup and thickness of the cup's rim will affect the umami, sweetness, smoothness, fragrance, and overall performance of the tea. The effect of preference for the cup was not found in this solution, which is not related to emotional responses to the stimuli in this group. Unlike the amateurs, the professionals' taste perception tended to not be influenced by their preferences regarding teacups.

The findings for both groups indicate that the mouth-feel of teacups (i.e., thickness of the cup's rim) has effect on the taste and flavor of tea. In a similar line of reasoning, and close to our findings, Van Rompay et al. [10] showed that a sour lemon sorbet ice cream was evaluated as even sourer when sampled from a cup with a sharp-feeling (rather than a smooth) surface texture.

4.3. Testing for Predictive Validity

To examine how well the model predicts the dependent variable and outcome in additional samples, the test of predictive validity is necessary [47]. The first step for predictive validity is to divide the sample randomly into a subsample and a holdout sample. The second step is to run the fs/QCA analysis for the subsample. Then the findings obtained should be tested against the holdout sample. The benefit of testing for predictive validity, including holdout samples, is that it always substantially increases the added value for both empirical positivistic and interpretative case studies [46]. After the findings are obtained from the subsample, the holdout sample must proceed with predictive validity testing. Then the author computes every solution from the findings from the testing with the subsample. Finally, the new variable is plotted against the outcome of interest using the holdout sample. The numbers below the "Plot" button show set-theoretic consistency scores [54]. If one of these two numbers indicates high consistency, the other can be interpreted as a coverage score. In this study, the solutions from the subsample for the control group are shown in Table 15, and the test of models from the subsample using data from the holdout sample for the control group is in Table 16. It can be said that models in the control group in this study have high predictive validity.

Table 15. Solutions from subsample for control group.

Function	Causal Solution	Raw Coverage	Unique Coverage	Consistency
y1 = f (x1, x2, x3, x4)	x2 *~x3 * x4	0.360	0.007	0.823
	x1 * x2 * x4	0.403	0.054	0.831
	x1 *~ x3 *~ x4	0.572	0.007	0.821
	x1 * x2 *~ x3	0.479	0.006	0.811
y2 = f (x1, x2, x3, x4)	x2 *~ x3 * x4	0.361	0.007	0.769
	x1 * x2 * x4	0.413	0.065	0.809
	x1 *~ x3 *~ x4	0.557	0.009	0.760
y3 = f (x1, x2, x3, x4)	x2 *~ x3 * x4	0.353	0.008	0.793
	x1 * x2 * x4	0.386	0.044	0.753
	x1 *~x3 *~ x4	0.564	0.009	0.767
y4 = f (x1, x2, x3, x4)	x2 *~ x3 * x4	0.370	0.009	0.832
	x1 * x2 * x4	0.416	0.0572	0.811
	x1 *~ x3 *~ x4	0.598	0.009	0.814
	x1 * x2 *~ x3	0.499	0.009	0.779
y5 = f (x1, x2, x3, x4)	x2 *~ x3 * x4	0.352	0.007	0.887
	x1 * x2 * x4	0.405	0.062	0.886
	x1 *~ x3 *~ x4	0.571	0.008	0.872
	x1* x2 *~ x3	0.485	0.008	0.848
y6 = f (x1, x2, x3, x4)	x2*~ x3 * x4	0.340	0.006	0.885
	x1 * x2 * x4	0.391	0.060	0.884
	x1 * ~ x3 *~ x4	0.558	0.007	0.881
	x1 * x2 *~ x3	0.474	0.008	0.857
y7 = f (x1, x2, x3, x4)	x2 *~ x3 * x4	0.352	0.008	0.858
	x1 * x2 * x4	0.4	0.059	0.847
	x1 *~ x3 *~ x4	0.575	0.008	0.848
	x1 * x2 *~ x3	0.486	0.011	0.821

Table 16. Test of models from subsample using data from holdout sample for control group.

Function	Model	Consistency	Unique Coverage
y1 = f (x1, x2, x3, x4)	Model1	0.804	0.68
	Model2	0.804	0.687
y2 = f (x1, x2, x3, x4)	Model1	0.919	0.34
	Model2	0.919	0.34
y3 = f (x1, x2, x3, x4)	Model1	0.964	0.337
	Model2	0.89	0.547
y4 = f (x1, x2, x3, x4)	Model1	0.964	0.337
	Model2	0.834	0.555
y5 = f (x1, x2, x3, x4)	Model1	0.910	0.344
	Model2	0.909	0.321
y6 = f (x1, x2, x3, x4)	Model1	0.909	0.321
	Model2	0.909	0.321
y7 = f (x1, x2, x3, x4)	Model1	0.858	0.518
	Model2	0.946	0.32

The test of predictive validity for the experimental group was operated by the previous process, and the results are shown in Tables 17 and 18. Compare the consistency and coverage and show that models in the experimental group in this study have high predictive validity.

Table 17. Solutions from subsample for experimental group.

Function	Causal Solution	Raw Coverage	Unique Coverage	Consistency
y1 = f (x1, x2, x3, x4)	x2 * x3 * x4	0.431	0.038	0.760
	~x3 * x4	0.531	0.0380	0.745
	~x1 * x2 * x4	0.41	0.0486	0.753
y2 = f (x1, x2, x3, x4)	x2 * x4	0.453	0.137	0.911
	x1 *~x3 *~x4	0.580	0.140	0.881
y3 = f (x1, x2, x3, x4)	x2 * x4	0.462	0.128	0.822
	x1 *~x3 *~x4	0.613	0.158	0.824
y4 = f (x1, x2, x3, x4)	x2 * x4	0.447	0.122	0.833
	x1 *~x3 *~x4	0.611	0.160	0.861
y5 = f (x1, x2, x3, x4)	~x1	0.693	0.0418	0.753
y6 = f (x1, x2, x3, x4)	x2 * x4	0.473	0.151	0.928
	x1 *~x3 *~x4	0.592	0.135	0.877
y7 = f (x1, x2, x3, x4)	x2 * x4	0.442	0.130	0.901
	x1 *~x3 *~x4	0.60	0.156	0.910

Table 18. Test of models from subsample using data from holdout sample for experimental group.

Function	Model	Consistency	Unique Coverage
y1 = f (x1, x2, x3, x4)	Model1	0.784	0.624
	Model2	0.871	0.282
y2 = f (x1, x2, x3, x4)	Model1	0.927	0.607
	Model2	0.871	0.282
y3 = f (x1, x2, x3, x4)	Model1	0.880	0.619
	Model2	0.801	0.278
y4 = f (x1, x2, x3, x4)	Model1	0.749	0.645
	Model2	0.730	0.310
y5 = f (x1, x2, x3, x4)	Model1	0.759	0.628
	Model2	0.740	0.301
y6 = f (x1, x2, x3, x4)	Model1	0.950	0.566
	Model2	0.950	0.566
y7 = f (x1, x2, x3, x4)	Model1	0.947	0.607
	Model2	0.928	0.293

4.4. Hypothesis Result

The results of a causal relationship between the control group and experimental group variables and the hypothesis of this study are summarized, as shown in Table 19.

Table 19. Fs/QCA causality analysis table for visual, tactile, and taste perception.

Experimental Group		Control Group	
Variables	**Hypothesis**	**Variables**	**Hypothesis**
x1 (Teacup shape preference)	H1 False	x1 (Teacup shape preference)	H1 True
x2 (Width of the teacup)	H2 **Partial True**	x2 (Width of the teacup)	H2 True
x3 (Height of the teacup)	H3 False	x3 (Height of the teacup)	H3 False
x4 (Thickness of the teacup)	H4 **Partial True**	x4 (Thickness of the teacup)	H4 True

Table 19 shows that teacup preference affects only the taste, fragrance, and overall tea performance in the control group. That is, non-professional tea drinkers' judgment regarding the taste and fragrance of tea tends to be influenced by their preference for teacups. For professionals of the experimental group, the taste, fragrance, and performance of the tea will not be affected by the teacup preference. The two groups of subjects unanimously found that visually observing the width of the teacup and the thickness of the teacup contacting or touching the lip will affect the umami, sweetness, smoothness, fragrance, and overall performance of the tea. One of the findings of both groups, the width of the teacup, is in line with Van Doorn et al.'s [52] research relating to the association of 'cup diameter', 'cup height', and 'cup thickness' with coffee taste expectations. They found that 'cup diameter' and 'cup height' influenced the coffee's characteristic aroma, bitterness, intensity, and sweetness, but the 'cup thickness' showed an impact on the temperature of the coffee only. In contrast to Van Doorn et al.'s work, the thickness of the teacup did have effect on the tea taste and fragrance in this present study. Despite some literature [52,55,56] suggesting that the flavor of coffee, beverage and tea is associated with the height of vessels, the present study found the height of teacup had no impact on tea taste and fragrance in both groups. Chinese tea is always hot, so the standard steps of drinking Chinese tea is to observe the tea color, smell it, and then taste it. It is possible the tall teacups do not seem easy for consumers to observe and smell, so hypothesis 3 is null.

This present study investigates the narrative statistical analysis (Table 20), indicating that the control group had a higher average score for tea taste and fragrance for Cup A.

Table 20. Percentage of measurement of tea performance results.

Experimental Group				Control Group			
Tea Taste Variables	**Cup Variables**	**f/Total**	**Pot**	**Tea Taste Variables**	**Cup Variables**	**f/Total**	**Pot**
Strongness	D	4/17	24	Strongness	B	8/17	41
Umami	B	10/17	59	Umami	A	9/17	53
Sweetness	B	7/17	50	Sweetness	A	10/17	59
Smoothness	D	8/17	41	Smoothness	A	11/17	65
Richness	D	8/17	41	Richness	A	7/17	50
Fragrance	A	14/17	82	Fragrance	A	13/17	76
Overall Performance	D	9/17	53	Overall Performance	A	11/17	65
Teacup Preference	D	14/17	82	Teacup Preference	B	9/17	53

Moreover, the fragrance for Cup A, the broadest and thickest cup shape among the five cups, also received the highest score for fragrance in the experimental group. Consistent with the results of Van Doorn et al. [52], the coffee in the broader cup was thought to be sweeter and aromatic but less intense. Van Doorn et al. also found that the effect of 'cup thickness' influenced coffee temperature expectations of participants from different countries. A seemingly logical interpretation of this study regarding 'cup thickness' is that the thicker the small Chinese teacup, the warmer the tea and the more intense and aromatic the tea. This is consistent with Harrar and Spence's [57] work on the association of spoon thickness and the perceived creaminess of the yogurt. Therefore, in terms of the performance of the tea taste, Cup A, with a constricted mouth and broad belly, can best express the taste and fragrance of tea for general consumers.

Although the teacup variables of the experimental group are relatively inconsistent, they still indicate some impact on different classes of tea taste. Delwiche and Pelchat [29] conducted a study with a blind test and found that professional wine tasters were also influenced by the visual image of the glass when judging the taste and aroma. Other related literature indicated that neither professionals nor amateurs could avoid being influenced by the tactile shape while tasting tea or wine [32,33].

Summing up, the following results are presented for both groups.

1. For those consumers who have no professional tea evaluation training, the larger the diameter of the cup, the taste and aroma of the tea will be better displayed. Also, the overall performance will be better if the height of the cup is not considered when one is drinking tea. Therefore, Cups A and B, which have only 0.1 cm difference in diameter and width, were the most recognized by general consumers regarding taste and olfactory perception of tea.
2. For regular consumers, their preference of teacup will directly affect the perception of all the tastes and fragrances of the tea. That is, the favorite cup shape will have a better tea taste and fragrance performance. Cup shapes that consumers like are affected by the diameter of the cup and the thickness of the cup's rim. The above data analysis found that the average preference of Cup A (3.471) and Cup B (3.647) was not much different, and Cup A in the tea soup taste and fragrance performance all stand out. Therefore, it is concluded that Cup A, with a large caliber and a thick rim, can adequately express the flavor and aroma of tea.
3. Data from the experimental group show that teacup preference is not in the causal combination. Therefore, it is concluded that professionals will not be affected by the taste and fragrance of tea due to teacup preference. However, in combination with factors affecting the taste and fragrance of tea, the diameter of the cup and the thickness of the rim of the cup are still sufficient conditions to affect the tea taste. Therefore, the researchers concluded that regardless of professional level, human vision and touch have a feeling of "sensation transference" to the taste system of taste and smell [35]. Cup D, with a relatively thin rim and smaller caliber, positively affected the tea test in the professional experimental group, but Cup A, with a thicker rim and larger caliber, also positively influenced the professional experimental group.
4. The experimental research found that consumers' vision and touch influence the taste system of taste and smell regardless of the degree of professionalism of tea, but the degree of influence is different. In particular, there are many types of Chinese tea, and the taste and fragrance are significant. Taking oolong tea in this study as an example, judging the quality of this tea is as crucial as judging its fragrance, so Cup A can be regarded as the best reference for the design of teacup shapes.

5. Conclusions

The essence of design is to solve the user's problem, make the user feel happy, and create a sense of happiness for the user. The essence of teacup design should be to solve the problem of drinking tea. The tea maker hopes to perfectly present tea tasting for consumers through a good cup design. Consumers hope that a good cup can make up for imperfect tea-making skills. Tea merchants who sell tea hope to satisfy consumers with tea taste through a good cup design and achieve a good sales performance of tea. However, the Chinese tea manufacturing process is complicated and the tea brewing technology is cumbersome. Therefore, in addition to solving the function of the tea carrier, the teacup design can change the user's sense of taste through the visual and tactile design of the teacup to produce pleasure and happiness, which is the value of the teacup design.

However, the current society faces a cultural crisis and a design crisis because many design practices are based on a small number of commercial interests and ignore potential system crises, similar to how the California government banned plastic toy ducks for causing cancer and congenital disability. Yet, the cultural and design background behind making such a product for children should be worth considering. Therefore, designers should rethink the environmental, social, and cultural responsibilities of product design. The concept of Actor-Network Theory (ANT; a social analysis method that believes that social science and social backgrounds interact with non-human actors to form a heterogeneous network, construct each other, and evolve), proposed by French sociologists Michel Callon and Bruno Latour in the mid-1980s, emphasizes the mutual construction and co-evolution of scientific practice and its social environment between people and non-human actors. The more highly modern society is, the more highly interactive the entanglement [58]. Therefore, nature and human society are not opposites but, instead, should find a social stability point in the interaction between human and non-human actors through human interaction. Producers, designers, users, earth's clay, energy, and environmental protection are intertwined to form a heterogeneous network in the ceramic industry. The interaction entangles the complex relationship between consumption, production, and environmental protection, especially between consumers and the environment.

When most studies are concerned with sustainable design issues, they tend to focus on product design to change user behavior, increase product lifespan, and reduce energy waste [58], or use the user experience to influence the behavior of other users [59]. Although our knowledge of how design changes behavior is rapidly expanding, we rarely discuss how to design products that meet the real needs of users and reduce design waste and excessive consumption. For example, under the pressure of environmental protection and sustainable development, teaware designers and producers focus more on resource reuse, product sustainability, or zero environmental pollution. Although ceramic teacups are consistent with sustainability and a long product life cycle, less environmental pollution and the non-reusability and excessive production and consumption of clay, coupled with the unique beauty of traditional firewood potters and consumers, have created an enormous carbon footprint in recent years. Thus, sustainable design appears to be empty talk. Unless manufacturers have the advantage of market interest, it is difficult to persuade them to accept sustainable design and reduce production. Tromp and Hekkert [60] discussed that the designer's social responsibility for the influence of design should emphasize the realization of desired consequences rather than the prevention of undesired ones. As a designer and one of the actors in the network, one should understand the social problems and dilemmas resulting from conflicts between personal interests and public interests brought about by the design of tea utensils. This research found that a teacup shape's visual and tactile sense impacts tastes and smell, which can provide teaware designers or ceramicists with a basis for innovative, creative production, solve user problems, and meet user needs. Consumers would have a reduced opportunity to choose inappropriate teacups and waste resources. Manufacturers can reduce the hoarding of improperly designed products and causes of environmental resources and profit depletion. In other words, if producers and designers design products based on the feelings and needs of consumers, users can use products that meet their needs, reduce the waste of clay in the ground, and protect the environment. Through this research, practical teaware design thinking fulfills the designer's social responsibility. Echoing the Actor-Network Theory, in the interaction between humans and non-humans, nature and society, the rearrangement of "people, circumstances, and things" seeks the organic balance of nature, society, culture, people, etc.

Limitation and Suggestions for Future Research

This study is an experimental study. The experimental group focuses on qualitative research by experts. However, compared to general consumers in the control group, qualified participants are few and older. Therefore, considering the complex relationship between factors, this study selected fs/QCA for small-sample analysis. Although empirical data in qualitative research function as a catalyst for constructing theoretical discussions [41], it is recommended that future research expand the experimental research sample and adopt quantitative analysis methods to increase its representativeness. In addition, we suggest redefining the tea test as being in line with the perception of general consumers and expanding the sample for general consumer quantitative survey methods to explore a broader evidence base and different opinions. This study has some limitations regarding the issues of the teacup's shape factors, the teacup's ceramic material, and the firing method. The chemicals used in glazing the teacup may all affect the taste and fragrance of the tea. As an experimental study, this study restricts the materials and colors of teacups as control items. Future research can explore the correlation between the same shape but different materials and colors and tea taste. The relationship between the research and firing methods of ceramic materials and the performance of tea soup is another issue of environmental sustainability. The social responsibility of tea set designers and researchers could be studied to promote the achievement of this goal.

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