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Developing and Testing a General Framework for Conducting Transdisciplinary Research

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Abstract: Complex societal problems cannot be resolved without transdisciplinary research (TDR). Currently, there is no focused communication platform or commonly shared research framework for conducting TDR. The current study is a continuation of the exploration of collaborations in multidisciplinary, interdisciplinary, and TDR to identify ideas that could contribute to developing and testing a general framework for conducting TDR. The systematic literature review in this study discovered three main themes (TDR initiation, TDR management, and transdisciplinary knowledge exchange). These themes formed three phases of a general framework for conducting TDR. The novelty of the presented phased general framework for conducting TDR relates to the type of learning and outputs that are required at the end of each related action of all associated stages of the three phases to enable all participants to participate in TDR. The logical sequence of these actions and associated stages and phases were verified through a survey of academics and industry professionals internationally. The findings evidenced that improved communication between academics and industry professionals can respond to complex societal problems such as sustainable development, global environmental change, and environmental crises. The findings of the current research will enable the development of a transdisciplinary collaboration framework (TCF) for the nature-based design (NBD) of sustainable buildings aligned with the Royal Institute of British Architects (RIBA) Plan of Work.

Keywords: transdisciplinary research; transdisciplinarity; transdisciplinary project; transdisciplinary approach; industry collaboration; academic-practice partnership

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1. Introduction

Collaboration in research is usually thought of as a partnership between two or more researchers to pursue mutually beneficial research. Research collaboration could be multidisciplinary (MDR), interdisciplinary (IDR), or transdisciplinary (TDR). MDR requires various disciplines to work independently to pursue a research goal causing it to be additive and not integrative [1]. IDR utilises a more integrative approach as researchers from different disciplines work together to learn from each other's fields of expertise and create opportunities such as participatory design for under-represented communities [2]. Academics in the same department with different expertise may work together on a sponsored project, whereas academics from different departments in the same faculty may work on an MDR project. TDR arises when researchers from various disciplines go beyond their separate theoretical and methodological conventions and orientations to develop common conceptual frameworks [3]. TDR is not a "new discipline" but a manner of seeing the world holistically [4].

Since the 1990s, sustainability has become an important factor for numerous research fields such as the built environment, which has required an increase in multidisciplinary collaboration [5]. Technological advancements have made these collaborations possible, and the history of past innovations suggests that these collaborations are desirable [6]. However, Cummings and Kiesler [6] highlighted that projects with principal investigators

from various disciplines did not suffer coordination losses and reported positive outcomes. Geographic dispersion rather than multidisciplinarity seemed to be more problematic. Technologically coordinated collaboration brought researchers together and reduced the negative impact of dispersion [6].

Societal problems are becoming complex and interdependent requiring the involvement of researchers from various disciplines to surpass methodological conventions and develop conceptual frameworks for TDR [3]. Funding calls are increasingly addressing complex societal challenges that need transdisciplinary teams and collaboration between industry and academia [7–9].

Transdisciplinary collaboration (TDC) between industry and academia supports improvement and innovation in industry and helps ensure industrial relevance in academic research [10]. A transdisciplinary collaboration framework (TCF) enables knowledge production due to the combination of scientific expertise developed through various insights in respective disciplines. A preceding study, its systematic literature review, and case study revealed that there is a lack of TDR because of limited communication among disciplines [11]. The current research investigates and explores TCFs that support knowledge transfer within academia and with industry and develops and tests a general framework for TDR. This exploration is needed to understand the state-of-the-art related to various frameworks for conducting TDR. The discoveries of this exploration will enable resolving complex societal problems including sustainable development. Brandt et al. [12] analysed peer-reviewed publications of transdisciplinary sustainability science and concluded that transformative and collaborative research is needed to realise sustainability science and resolve urgent sustainability problems, noting that there is no focused communication platform and no commonly shared research framework. The research in our current paper is novel because it presents a phased general framework for conducting transdisciplinary research and indicates what knowledge should be acquired by the participants in transdisciplinary research to enable successful completion of the processes within each of the three phases (initiation, management, and knowledge sharing). The overarching research aim of the current doctoral research is to develop and test a TCF for the NBD of sustainable buildings. The general TDR framework that is presented in this paper is considered as a prerequisite for developing a bespoke TCF for the NBD, which will be presented in a subsequent paper.

The design of a general TCF requires a wider study of published technical reports and research papers by academic associations or organisations that support TDCs and their management. After the identification of key elements from different disciplines and their interrelationship, a workflow of actions is developed for establishing and managing TDR and its dissemination. The workflow of a TCF entails the following steps: (1) identifying a problem and its programmatic, functional, and regional context, (2) determining if the problem is associated with academia or academia and industry, (3) mapping and classifying all the disciplines to understand how TDR could take place, (4) creating a multidisciplinary team and identifying key stakeholders, (5) developing the co-design and participatory strategies for TDR collaboration, (6) implementing the strategy through efficient and effective research management, (7) undertaking TDR, and (8) disseminating research findings for scientific reflection and re-problematisation.

The next section explains the research methods in more detail. The literature review is presented in Section 3. A general framework for TDR, its phases, associated stages, and related actions are presented in Section 4. Section 5 presents the validation of the proposed general framework for conducting TDR. A discussion of the research findings is presented in Section 6. Section 7 presents the conclusions and potential further research.

2. Materials and Methods

A systematic literature review (SLR) [13–15] was conducted to identify studies particular to various TCFs for the NBD of the sustainable built environment (SBE), the overarching research aim. The search strings “TCF for knowledge transfer”, “TCF for engagement with

industry", "TCF for nature-based design", and "TCF for SBE" were used for collecting studies indexed on JSTOR, ScienceDirect, Google Scholar, and Web of Science identifying 15,139 studies. The next step was to delete duplicates, followed by screening by keywords from other fields (e.g., medicine, drugs, proteins, and cancer). A total of 6796 studies were scanned by their titles and abstracts, leaving 2182 studies for which inclusion and exclusion criteria were established. The inclusion criteria encompassed online accessibility of research papers published in English and related to transdisciplinarity, knowledge transfer, engagement with industry, NBD, nature-based solutions (NBSs), and sustainable buildings. The exclusion criteria entailed research papers from other fields such as manufacturing, anthropology, business, commerce, and medical sciences. Forty studies were included in the literature review. The identified studies were used to discover three main themes of the literature review and to propose phases of a general framework for TDR. This framework was tested through a recorded presentation on the proposed general framework for TDR and a survey of academics and industry professionals who had seen the presentation.

3. Literature Review

The following themes were identified in the literature review: (1) TDR initiation, (2) TDR management, and (3) transdisciplinary knowledge exchange.

3.1. TDR Initiation

The identified approaches for initiating TDR are presented in this section.

Levin and Cross [16] tested the mediating role of trust in effective knowledge transfer for TCFs. Their theoretical framework tested tie strength, perceived trustworthiness, and receipt of beneficial knowledge using a model of two-party dyadic knowledge exchange. Their findings showed that strong ties and receipt of useful knowledge were mediated by competence and benevolence-based trust, highlighting the structural benefits of weak ties and competence-based trust for the receipt of tacit knowledge.

Design schools create collaborative learning environments where diverse student groups develop and share interdisciplinary and transdisciplinary knowledge to ensure that graduates thrive and succeed in diversified global design companies [17]. A field study of graduate students from architecture, industrial design, and visual communication design showed discipline-specific methods and the willingness for engaging in collaborative and reflective activities [17]. These activities developed a mediated design space called the LifeSampler Design Studio (LSDS), which enabled small group collaborations to capture, annotate, and archive activities in a design studio environment [17]. LSDS built an informal design environment providing a forum to increase the awareness of best practices across design disciplines. Technological and computational advances allowed high levels of sharing of creative outcomes supporting TDC [17].

Complex environmental problem-solving relies on cross-disciplinary and TDC among scientists [18]. Cross-disciplinary or TDC research needs to be preceded by an exploratory phase of collective thinking to develop conceptual frameworks. Pennington [18] applied three perspectives on learning that enabled cross-disciplinary collaboration: the hierarchy of needs, constructivism, and organisational learning. Pennington [18] explained that collaboration is a complex system of people, scientific theory, and tools that need management. Effective collaboration management requires leaders who are facilitators and capable of orchestrating effective environments.

Young researchers often underestimate the challenges of IDR/TDR and do not spend enough time to overcome differences and create a common ground, which leads to frustration, unresolved conflicts, and in the worst situations, discontinued work [19]. A framework was designed to initiate a process necessary for successful IDR and to separate epistemological differences from cultural differences, proposing to induce discussions about quality and credibility through the following questions: (1) is the study area sufficiently and coherently demarked; (2) is the study sufficiently anchored in relevant literature in terms of framing, methodology, and analysis; (3) has the information been collected reliably, and

is it of sufficient quality; (4) is the information analysed with an informed and reflective approach; and (5) are the form and structure consistent with agreed norms and does the text consistently follow the chosen form and structure [19]? Evaluating these questions alone or in a group stimulates reflection and increases awareness of one's perspective, and facilitates dialogue, collaboration, and the creation of common ground.

The strength of integration varies from interdisciplinarity to transdisciplinarity, as the latter consists of the involvement of non-academic actors and stakeholders in the research process [20]. Knowledge related to the research on 'Future Earth' could be integrated by using scientific, international, and sectoral dimensions within an iterative framework for knowledge integration that supports the process of knowledge co-creation and consists of three fundamental steps through which academia and stakeholders are involved in varying degrees: co-design, coproduction, and co-dissemination [20].

Fully developed, well-structured transdisciplinary case studies are needed to initiate and support the reorientation of scientific research in the complex, dynamic, and uncertain social system of universities. These case studies could bring together scientists in two combination types resulting in a high-performing TDR team: (1) one member of the team serves as a broker among all the represented disciplines and facilitates communication and cross-fertilisation of ideas across disciplines; and (2) multiple members serve as brokers across different disciplines [21].

As government agencies, educational and research organisations, businesses, and industry promote IDR to address some of the most challenging economic, health, environmental and societal issues, higher education institutions (HEIs) need to provide students with training and experience in IDR, areas of responsible research conduct, and the dynamics of the mentor–mentee relationship [22].

TDR approaches have focused on increasing non-academic participation in knowledge production processes related to practice-based and real-life contexts [23]. The related transdisciplinary co-production framework identified primary methods for co-production such as joint data collection, co-leadership, and co-authorship [23]. The primary methods for data collection included seminars, focus groups, public workshops, student projects, stakeholder meetings, design workshops, and student trials. Transdisciplinary co-production increases the usability of results due to accessibility and relevance but does not anchor institutional or political contexts where societal change develops [23].

HEIs in Albania and Kosovo have extensively invested in research and strategy development to tackle regional sustainability challenges [24]. The ConSus (Connecting Science-Society Collaboration for Sustainability Innovation) project focused on the effort of HEIs to tackle regional sustainability challenges towards systemic, holistic solutions for sustainability by providing mutual learning opportunities. It ensured interdisciplinary or TDC towards regional development and innovation, the derivation of courses, training sessions, teaching material, and a collaboration network of HEIs and regional stakeholders [24].

Steger et al. [25] presented the management of an ecosystem services framework to facilitate transdisciplinarity across disciplines. The transdisciplinary elements should be categorized very early in the research process to ensure diverse objectives have equal weighting. The initiation inclusion of transdisciplinary elements is imperative for transdisciplinary action-oriented research as the final objectives for researchers (advancing theory) are likely to differ from the end goal of stakeholders (addressing social injustice) involved in collaboration.

These efforts can be enhanced by joint-knowledge platforms, such as Oppla, that provide wider access and respond to the fragmentation of data, methods, tools, expertise, and scientific knowledge related to natural capital and ecosystem services [26]. Oppla acts as a marketplace and community due to its content (documents, cases, tools, instruments, services, training, education, networking, news, and events) and fosters efficient use of research funds as it provides a freely available platform for existing and new natural capital and ecosystem service projects and their outcomes.

IDR/TDR workshops [22] could include the perspectives of social sciences and humanities in engineering education to facilitate the adoption of transdisciplinary approaches [27]. Future sustainable engineering programmes embracing transdisciplinarity would develop critically thinking engineers who reflect and rework public welfare construction and understand natural cycles and technological systems management [27]. Knickel et al.'s [28] transdisciplinary co-learning framework, with its four dimensions and 44 criteria, covered all aspects of TDC at a project level as it assesses progress and encourages continuous improvement and reflection of research processes. It is highly beneficial for the planning and implementation of all multi-actor, interactive, innovative, transformative, and action-oriented research projects [28].

A 3-year collaborative research project—TransImpact (Effective Transdisciplinary Research)—investigated the application of practices and methods, in transdisciplinary projects with a societal and scientific impact. Sixteen out of seventy-five finalized TDR projects were selected for a detailed case study analysis assuring a high diversity of (1) topics in sustainability research and neighboring fields, (2) funding bodies (public/private; EU/national/regional), (3) project leads (university/non-university), and (4) research formats and methods [29]. The selected case studies were clustered into themes focused on problem definition, participation, knowledge integration, and transferability. For adaptive shaping of TDR processes that foster the potential for societal effects, five main categories were defined: problem relevance, connectivity, roles and responsibility, interests and concerns, and collaboration culture [29]. Their analysis reflected that the identification, observation, and understanding of interests across actors from science and society are necessary for TDR practice.

Matthews et al.' [30] framework for constructive sustainability assessment (CSA) enabled the application of sustainability assessment of emerging technologies. Its four design principles included anticipation, exploring uncertainty, opening-up, and transdisciplinarity, followed when using sustainability assessments of emerging technologies. Their framework relied on formulating the sustainability assessment, evaluating sustainability implications, and interpreting results, and facilitated a crucial response for the governance of emerging technologies towards sustainability [30].

Nix et al. [31] explained how participatory action research (PAR) integrated different disciplines in TDR collaboration to identify healthy and sustainable housing solutions for local development practices and policy. The three-stage PAR focused on problem identification; designing solutions; and implementation, monitoring, and evaluation. As PAR integrates different disciplines and faces several challenges, Nix et al. [31] provided recommendations for successful implementation, such as: commencing with a collaboration workshop and team field visit; developing an effective communication framework; adapting and being prepared for flexibility; pre-allocating time for reflection and assessment of validity; and providing dedicated training and support to researchers.

Collaborative learning environments for transdisciplinarity are aided by Gardiner's [32] framework that supports synergetic thinking in an educational context and helps students solve complex problems as its five components include epistemic awareness, epistemic control, epistemic empathy, epistemic humility, and a collaborative creative way of knowing. The framework normalizes collaborative decision-making and collaborative understanding, with it becoming part of upper-secondary, undergraduate, and postgraduate learning throughout the world [32].

Gottwald et al. [33] tested Geodesign as a planning-support process that facilitated participatory planning and boundary management between participants from science and practice. It led to spatial NBS scenarios and several contributions to boundary management: (1) translation of scenarios into maps differing in stakeholder involvement, (2) easier facilitation of communication, and (3) feedback system tool for mediation that led to frustration due to complexity. Policymakers should utilise opportunities for applying transdisciplinary spatial planning processes to integrate diverse perspectives and co-generate knowledge for

sustainable river landscape development providing benefits to the public and the natural environment [33].

Tools and applications have been combined to form living labs, offering collaborative research and development environments targeting societal challenges [34]. Their framework was based on co-creation principles consisting of four stages: stakeholder mapping, scope definition, strategic impact mapping, and roadmap definition, with them having an iterative approach and feedback loops due to the dynamic nature of TDR collaboration. The success of TDR collaboration relies on interpersonal qualities and the traits of collaborating parties, e.g., openness, an innovation mindset, and a willingness to share and embrace transdisciplinary ethics.

Malekpour et al. [35] identified the knowledge gap of limited guidance for the design of collaborative governance for delivering NBSs and proposed a framework offering key principles and considerations for designing collaborations on NBSs. The framework focuses on upfront planning to consider the expected outcomes (the why), assesses the operating environment/context (the what), engages with actors and stakeholders at the required level of influence (the who), and uses fit-for-purpose processes for interaction (the how) [35]. The framework highlighted elements for consideration with the intended level of impact, methods for categorising participants, and different levels of collaboration in infrastructure and urban planning.

3.2. TDR Management

Bammer [36] explored three areas of IDR/TDR collaborations, which included harnessing differences, setting defensible boundaries, and gaining legitimate authorisation, and presented the elements essential to any collaboration: (1) the management of differences that may damage partnerships; (2) decision-making regarding what the collaboration would encompass; (3) understanding and accommodating forces that may distort what the collaboration is set to achieve; and (4) the classification of essential supporters while maintaining research independence.

The building sector is the largest industrial sector in the US and Europe and built environment is responsible for negative environmental impacts due to energy use, material extraction, waste production, and land conversion [37]. The related analytical framework, aided by ecosystem theory from thirteen disciplines, facilitated demarcating boundaries to problems for analyzing and solving them and showed how problems and solutions at one spatial scale always connect with those on higher and lower scales. Van Bueren et al.'s [37] framework also showed how sustainability is a 'wicked' problem as some problems need to be addressed in connection to other problems. A particular solution to a problem will have a positive or negative impact on other problems, addressed by other stakeholders. An appropriate example is green roofs addressing a range of problems affecting multiple subsystems at several spatial scales.

Angelstam et al.'s [38] seven-step TDR framework used multiple landscape case studies for knowledge production and learning to support the development of accounting systems for ecological, economic, and socio-cultural dimensions of sustainability. It responded to measuring and assessing sustainability dimensions through performance targets for information transparency and by developing adaptive governance at several levels for managing large geographical areas across scales.

For a university to be a change agent supporting transdisciplinarity, the presence of knowledge would not be sufficient, but universities need to extend knowledge ownership within local and regional communities [39]. Universities need to consider collaborative research methods and education in informal learning environments [17] to ensure knowledge demand, transfer, and generation are collectively shared between local and regional societies and universities [39].

Universities are increasingly engaging in multi-stakeholder collaboration for co-creating knowledge, experiments, and tools with social and technical systems to advance societal sustainability [40]. Most of these conceived initiatives primarily entail faculty re-

search projects; however, Trencher et al. [40] highlighted that much less attention is paid to knowledge co-creation for student sustainability learning and education. A framework of four models (masters or doctoral research; social experiments and stakeholder interactions; faculty research assistance; and project planning and management) was designed, which examined knowledge co-creation and social experiments' contribution to sustainability learning [40].

Mitchell et al.'s [41] TDR programme (Landscape and Policy Hub) and its evaluation focused on fostering transdisciplinarity, emphasing communication that entails effective knowledge brokering, regular face-to-face meetings using participatory activities, and shared field engagements that enhanced transdisciplinary interactions between researchers and research users. Their recommendations for developing large collaborative TDR projects showed the link between IDR and TDR as the research affirmed that forming IDR teams enables the proactive pursuit of identification and integration of all scientific disciplines in the TDR project by mapping the contributions of all disciplines [41].

Velenturf et al. [42] designed the Resource Recovery from Waste programme (RRfW) to promote the transition to waste and resource management in a circular economy, restoring the environment, generating public benefits, and promoting clean growth by engaging relevant actors and stakeholders from academia, government, and industry to co-develop a shared perspective and approach for this transition. Such programmes enable the development of themes, identification of regulatory instruments (taxation and tax breaks, reporting, extended producer and consumer responsibility, product bans/product standards, mandatory recycling regimes, and waste prevention acts), and the development of a policy framework for effective academic–government collaboration [42].

It is challenging to differentiate between what can be considered as nature or natural and what cannot be [43]. This concern is necessary for both the level of human intervention in ecosystem processes considered acceptable and the inclusion within NBSs of actions inspired by nature, such as biomimicry. Calliari et al. [43] proposed an assessment framework suitable for multifunctionality, simultaneously delivering environmental, economic, and social benefits; cost-effectiveness; and co-production of scientifically sound knowledge through multi-stakeholder engagement. The framework's scope considered solutions based on ecosystem services and not just those inspired by nature. The framework focused on living components of ecosystems in relation to NBSs that are climate-proof, i.e., those that can deliver expected outcomes under predicted future climate conditions. Calliari et al. [43] highlighted that the framework's application relies on transdisciplinary multi-sectoral knowledge and tools and the close engagement of multiple stakeholders. Knowledge co-production practices in various contexts allowed detailed recommendations applicable to nature-based interventions, such as an enabling environment supported by social dialogue and cross-sectoral partnership; institutional support for social innovation; and support for intermediaries that bring together diverse stakeholder views assisting the shift from top-down to collective leadership.

NBSs have been promoted as adaptive measures against increasing hydrometeorological hazards, such as heatwaves and floods causing economic damage and loss of life in all parts of the world [44]. Transdisciplinary approaches have been crucial for designing and implementing an environmentally, economically, technically, and socio-culturally sustainable NBSs. The key processes for the operationalisation of NBSs include co-planning (identification of the main hazards, impact modelling and scenario modelling, the selection of most suitable sets of NBSs and socio-institutional measures); co-design (co-development, testing, and demonstration and a policy framework for NBS implementation), and co-management (NBS implementation and monitoring and evaluation of NBS projects) [20,44].

3.3. Transdisciplinary Knowledge Exchange

The concept of knowledge transfer is challenged as sustainable ecosystem management depends on diverse and multi-faceted knowledge systems continuously being updated to

reflect current understanding and needs [45]. Knowledge transfer is much less effective than knowledge co-production as it needs knowledge interfacing and sharing, shifting from viewing knowledge as a transferrable element to viewing knowledge as a process involving negotiation among all participants [45].

The need for integrative (interdisciplinary or transdisciplinary) approaches has increased the number of Ph.D. students in the field of environmental and landscape change [46]. Ph.D. students lacked a differentiated understanding of various integrative approaches (IDR/TDR); and the primary motivation to join integrative projects was their dissertation subject, the intellectual stimulation of working with several disciplines, and the belief that integrative research is comparatively more innovative [46]. They suggested improving knowledge regarding interdisciplinary or transdisciplinary approaches, balancing practical applicability with theoretical progress, giving formal introductions to other research fields, and further developing institutional support for integrative Ph.D. projects.

Although IDR/TDR projects are unique, TDR teams often work in volatile, uncertain, complex, and ambiguous contexts that often show that the problem and solution are unclear, requiring shared conceptualisation [47]. To avoid these problems, IDR/TDR teams should have a shared commitment to finding a solution to a problem; deep knowledge in various fields; a shared ethical and value system for collaborative engagement within the research team; a position with highly connected knowledge networks; and institutional access to funding, material, experimental, and technological resources [47].

Bochenina et al. [48] agreed with Peer and Stoeglehner [39] as interdisciplinary/transdisciplinary education and research are intricately connected with the knowledge requirements of a society. Increased diversity of knowledge areas would ensure solutions to complex societal problems by training specialists with specific skills in collaborative interactions at a high abstraction level [48].

The triple helix model of knowledge, industry, and government relationships is one of the most comprehensive attempts to describe the altering institutional frameworks for innovation and growth, especially concerning urban and regional contexts [49]. Comunian et al. [49] suggested that universities possess long associations with urban and regional creative activities; however, critical institutional and professional challenges prevail in developing an explicit and sustainable role as new actors in urban and regional creative economies. The nature of these challenges derives complex dynamics of knowledge creation—practice relationships found in arts and humanities disciplines [49]. The interactions between art and the humanities, the research base in higher education, and cultural and creative industries continue to define new knowledge exchange processes through novel organisation forms, partnerships, reflexivity, and transdisciplinarity [49].

Huchzermeyer and Misselwitz [50] presented the Co-op City Network—Housing for Sustainable Urban Futures (COCINET), which included social scientists, planners, and practitioners and generated comparisons and exchanges across distinct experiences. Its regional workshops brought together academic and non-academic urban knowledge producers (residents, activists, practitioners, experts, researchers, and policymakers) focusing on the regional context of their respective countries. The study highlighted that increased advocacy roles of academia, embracing social and planning scientists to engage with transdisciplinary partnerships, is needed.

Local and regional communities, significant participants of all TDR projects, could be supported by horizontal knowledge exchange as it enables community-owned solutions, empowering successful and sustainable environmental management due to shared conceptual and technical understanding [51]. Miszczak and Patel [52] confirmed the findings of Tschirhart et al.'s [51] research as they mentioned that a single knowledge base is not satisfactory and responsive enough to the constantly altering nature of urban and environmental changes. Committed and engaged interactions, such as knowledge co-production approaches between academicians and practitioners, result in multiple benefits such as deepening partnerships, building trust, and transpiring tacit knowledge, dependent on intermediaries facilitating, convening, and mediating relationships. Dang et al. [53] found

out that Australian universities use both formal (research centers, incubators, and contract-research and commercialism) and informal channels (internships, mentoring, industry talks, TDR platforms, collaborative Ph.D. programmes, and industry training programmes) to transfer knowledge between industrial partners.

Formative and summative evaluation of knowledge transfer processes would increase the quality of TDR projects by guiding the adoption of tools and methods [54]. The identified principles of successful knowledge transfer include (1) establishing an appropriate process; (2) delivering a meaningful impact; (3) aligning with institutional values; and (4) creating added value for scientific institutions and society [54].

Daniels et al. [55] described the Tandem framework, consisting of structured elements and practical guiding questions informed by empirical analysis, that laid the foundation of science-informed policy and policy-informed science. The framework aimed to: (1) improve ways in which all participants work together to purposefully design transdisciplinary knowledge integration processes (co-production processes that bring together different knowledge types across the science–society interface); (2) co-exploration of decision-relevant needs for the co-production of integrated climate information; (3) and an increase of individual and institutional capacities, collaboration, communication, and networks that can diffuse information for climate-resilient decision-making and action [55]. Transdisciplinary knowledge integration journeys, if taken in partnership, build skills, strength, flexibility, coordination, and efficient communication.

3.4. Summary and Knowledge Gaps

This section summarises the research related to TCFs to support knowledge transfer within academia and engagement with industry overarched by the following themes: initiation, management, and knowledge exchange. The collected ideas and characteristics are crucial for developing the TCF for the NBD of sustainable buildings, initiating TDR, managing TDR, and transdisciplinary knowledge exchange.

Regarding TDR initiation, the most significant contributing ideas are related to creating a common ground [19]; co-design [20]; joint problem formulation and project design [23,30]; workshops on interdisciplinary research, areas of responsible research conduct, and mentor–mentee relationships [22]. Other ideas included common language that can be used in various disciplines by environmental managers and within global markets [25]; problem identification, problem relevance, connectivity, roles and responsibility, interests and concerns, and collaboration culture [29,31]; stakeholder mapping, scope definition, strategic impact mapping, and roadmap definition [34]; and methods of categorising participants [35].

Researchers have also presented various ideas for efficient TDR management, including managing differences that may damage partnerships, decision-making regarding collaboration, understanding collaborative forces, classification of essential supporters [36]; highlighting stakeholders' use and non-use values; analysing institutions, policies, and governance; measuring ecological, economic, social, and cultural sustainability [38]; utilising scientific dimension, international dimension, and sectoral dimension [20,44].

In relation to transdisciplinary knowledge exchange, the most crucial concepts comprised knowledge interfacing and sharing [45]. Another aspect is that IDR/TDR team members should have an ethical and value system for collaborative engagement within the research team, a position in highly connected knowledge networks, and institutional access to funding, material, experimental, and technological resources [47]. Transdisciplinary knowledge exchange also relies on a high level of stakeholder participation promoting knowledge integration and reflexive learning across diverse sectors and disciplines [23]; academic and non-academic urban knowledge producers (residents, activists, practitioners, experts, researchers, and policymakers) focussing on the regional context of their respective countries [50]; and formal and informal knowledge transfer processes [53]. Using the transdisciplinary co-learning framework and identifying intended and unintended outputs, effects, outcomes, and impacts [28]; formative and summative evaluation of knowledge transfer processes [54]; and transdisciplinary knowledge integration pro-

cesses (co-production processes that bring together different knowledge types across the science–society interface) [55] are essential for transdisciplinary knowledge exchange.

Currently, there is no phased general framework for conducting TDR with associated stages and related actions for initiating TDR, managing TDR, and transdisciplinary knowledge exchange. The next section presents a general framework for conducting TDR. It highlights its three phases: TDR initiation, TDR management, and transdisciplinary knowledge exchange. Each phase has three associated stages explained in detail in the subsequent sections.

4. A General Framework for Conducting TDR

Ideas from the academic sources presented in the literature review enabled the design of a general framework for conducting TDR. A general framework for TDR aims to overcome the disparity between society, the biophysical world, and the ecological, social, and economic dimensions of development [56]. Sustainability inherently needs the involvement of TDR practices to enable TDR initiation, TDR management, and transdisciplinary knowledge exchange. Each phase has three associated stages explained in the subsequent sections.

4.1. TDR Initiation

Successful TDR initiation would need three associated stages (Figure 1). The first associated stage (skills development) would entail an exploration of collective thinking, the hierarchy of needs, and organisational learning [18] by the principal investigator and co-investigators (1). This stage is needed for successful initial collaboration and skills development (2). It is followed by forming collaborative learning environments, thinking skills, communication, and empathy skills (2) [27,32]. Reflecting on these experiences from collaborative learning environments and for knowledge transfer, it is pivotal to organise workshops on interdisciplinary research, conducting responsible research, and the mentor–mentee relationship (3) [22].

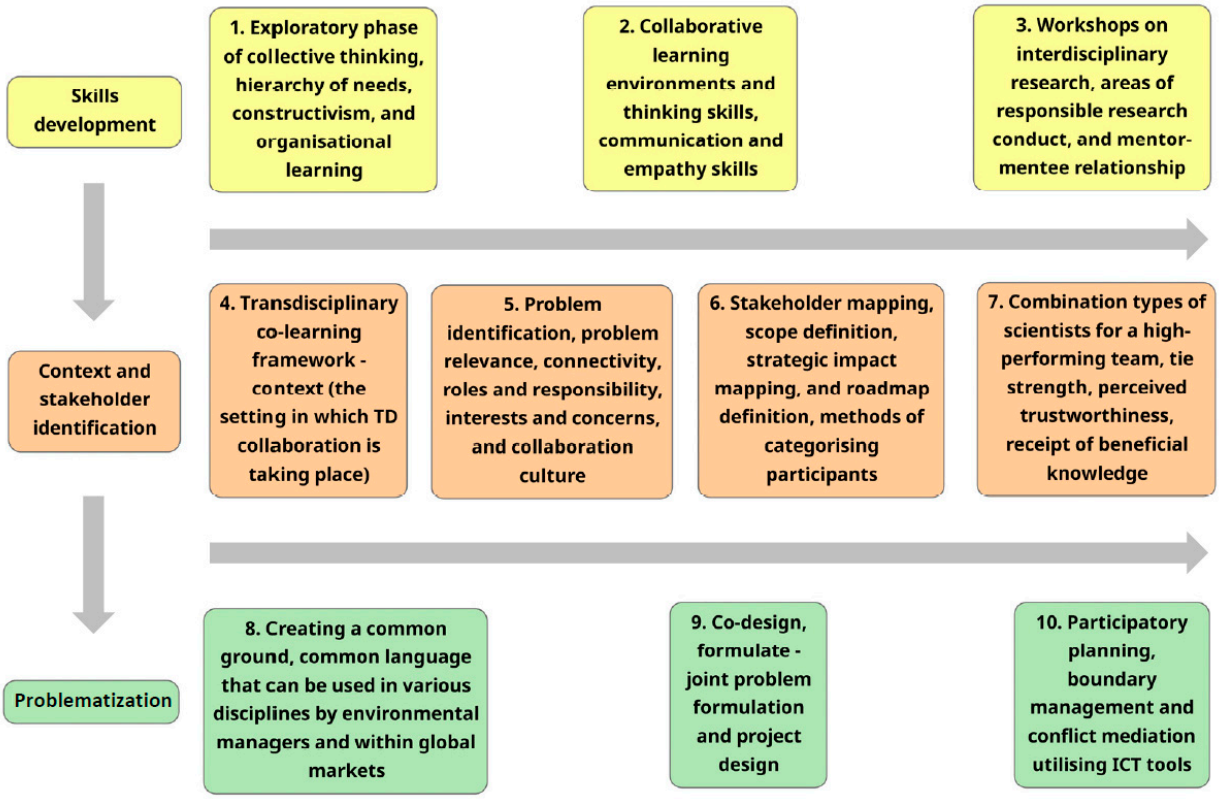

Figure 1. Phased flow of actions for successful TDR initiation.

The second associated stage (context and stakeholder identification) comprises the setting and context in which the transdisciplinary collaboration needs to take place (4) [28]. At this stage, problems need to be identified, in relation to relevance, connectivity, roles and responsibility, interests, and concerns (5) [29,31]. Problem identification, stakeholder mapping, and scope need to be defined for categorising participants (6) [34,35]. To categorise participants and form IDR/TDR teams, the principal investigator needs to study various combination types of scientists/participants for a high-performing team and understand concepts such as tie strength, perceived trustworthiness, and receipt of beneficial knowledge (7) [16,21].

The third stage (problematisation) includes creating a common ground and a common language that can be used in various disciplines within global markets (8) [19,25]. The creation of common ground would assist in joint problem formulation and project design (9) [23,30]. This stage would need participatory planning, boundary management, and conflict mediation using ICT tools (10) [26,33]. The implementation of these three stages should ensure successful TDR initiation.

4.2. TDR Management

Like TDR initiation, successful TDR management is achieved through three associated stages (Figure 2). The first associated stage builds from the last phase of TDR initiation and consists of managing differences that may damage partnerships, decision-making regarding collaboration, and understanding collaborative forces (1) [36]. This associated stage needs demarcating boundaries to problems for analyzing and solving them and identifying scientific, international, and sectoral dimensions (2) [20,37]. Following boundary demarcation, the categorisation of participants based on the level of collaboration is needed for stakeholder alignment (3) [33–35].

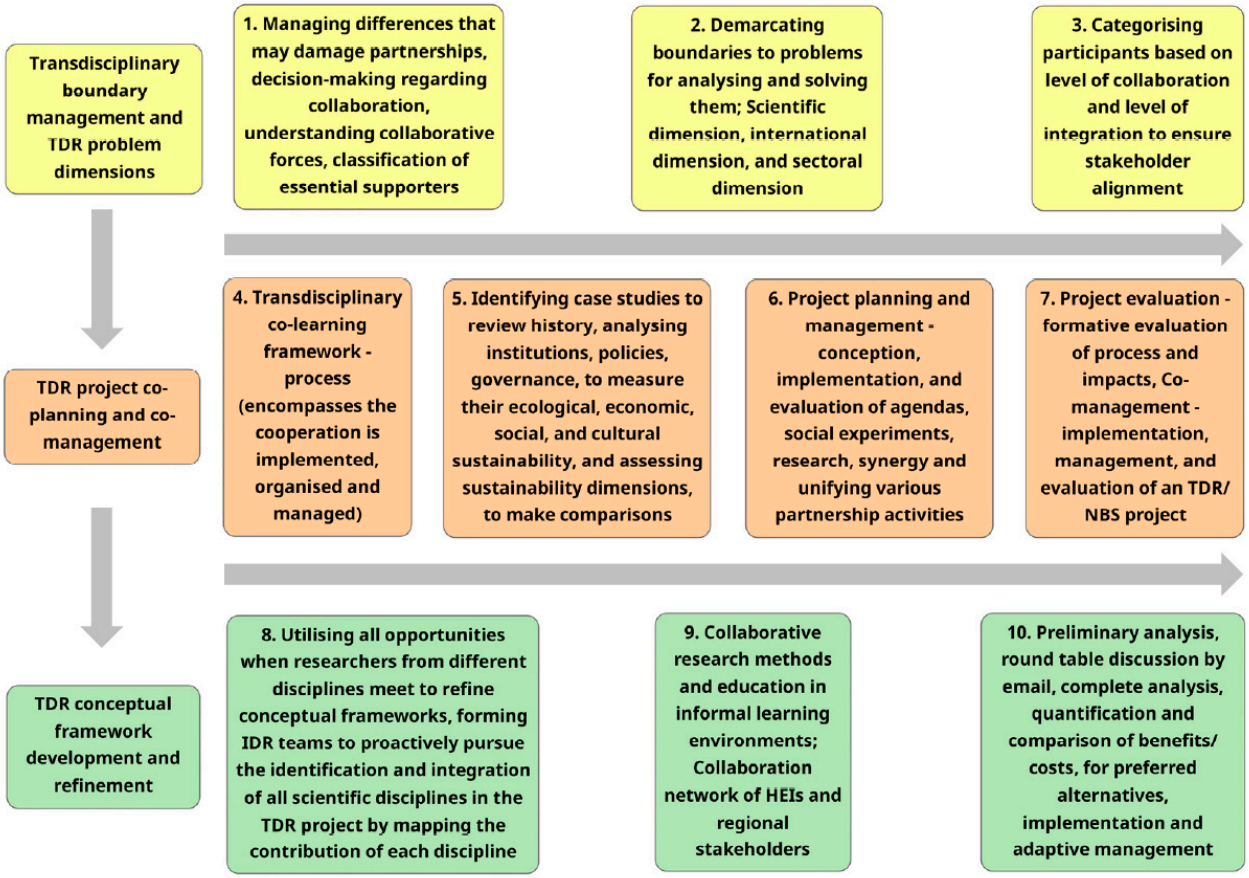

Figure 2. Phased flow of actions for successful TDR management.

The second associated stage focuses on how the cooperation of participants would be implemented, organized, and managed (4) [28]. For context, it would need to review case studies, analyse institutions, policies, and governance, and make comparisons (5) [38]. The second associated stage would further require project planning and management, entailing conception, implementation, and social experiments, unifying various partnership activities (6) for successful formative evaluation of the process and impacts of a TDR project (7) [23,40,44].

The third associated stage involves utilising all opportunities to refine conceptual frameworks and the formation of IDR teams to proactively pursue the identification and integration of all scientific disciplines in the TDR project and map the contributions of each discipline (8) and to set up a collaboration network of HEIs and regional stakeholders (9) [24,41]. Finally, a preliminary analysis, through round table discussions or by email and a comparison of benefits/costs for preferred alternatives, implementation, and adaptive management are needed (10) [42,43]. The application of these three phases should ensure effective and efficient TDR management.

4.3. Transdisciplinary Knowledge Exchange

Novel transdisciplinary knowledge exchange (Figure 3) needs nurturing stakeholder relations, community consensus, and implementing various social experiments (1) [40] enabled through several intermediaries, facilitating, convening, and mediating relationships (1) [52]. Participants need knowledge interfacing and sharing to balance practical applicability with theoretical progress (2) [45,46]. At this associated stage, IDR/TDR team members should develop an ethical system for collaborative engagement within their research team (3) [47].

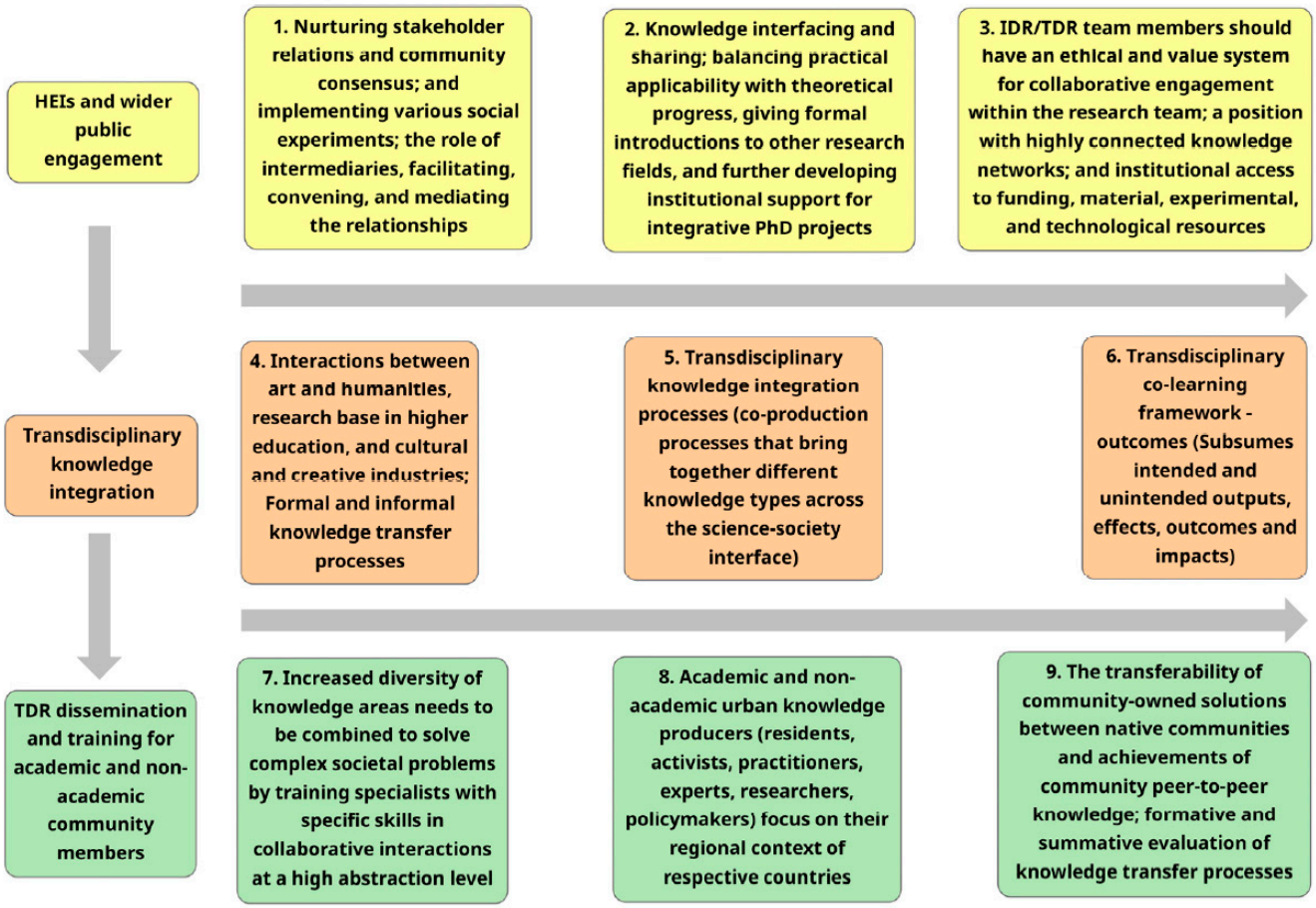

Figure 3. Phased flow of actions for successful transdisciplinary knowledge exchange.

The second associated stage needs interaction between arts and the humanities and the utilisation of formal and informal knowledge processes (4) [49,53]. This stage would need co-production processes bringing together different knowledge types across the science–society interface (5) [55]. That stage would subsume intended and unintended outputs, effects, outcomes, and impacts (6) [28].

The final associated stage focuses on the increased diversity of knowledge required for solving complex societal problems (7) [48] with the support of academic and non-academic urban knowledge producers (residents, activists, practitioners, experts, researchers, and policymakers) focusing on the previously established regional contexts (8) [50]. Transdisciplinary knowledge exchange would rely on community-owned solutions, achievements of community peer-to-peer knowledge, and summative evaluation of knowledge transfer processes (9) [51,54].

These associated stages should ensure high-quality transdisciplinary knowledge exchange. Section 4.4 highlights the suggested outputs based on all the associated stages of all phases. Section 5 presents the validation of the general framework for transdisciplinary research.

4.4. Suggested Outputs

This subsection highlights the suggested outputs for the abovementioned associated stages related to all three phases (TDR initiation, TDR management, and transdisciplinary knowledge exchange). These suggested outputs (Table 1) would enable academics, researchers, industry professionals, and the wider public to know what is required at the end of each phase and its related associated stages.

Table 1. TDR phases, associated stages, and suggested outputs.

TDR Phases and Suggested Outputs		
TDR Phase	**Associated Stage and Actions**	**Suggested Outputs**
1. TDR initiation	1.1. Skills development (1, 2, 3)	1.1.1. Recommendations on collaborative learning environments, responsible research, and innovation and interdisciplinary working
	1.2. Context and stakeholder identification (4, 5, 6, 7)	1.2.1. Diagrams: Innovation ecosystems (1) and finalised combination type of scientists/researchers for IDR teams of the TDR project (2)
	1.3. Problematisation (8, 9, 10)	1.3.1. Formulated joint TDR problem
2. TDR management	2.1. Transdisciplinary boundary management and TDR problem dimensions (1, 2, 3)	2.1.1. Diagrams: Scientific, international, and sectoral dimensions of the TDR problem (1) and stakeholder mapping (2)
	2.2. TDR project co-planning and co-management (4, 5, 6, 7)	2.2.1. Overview of key lessons learned: case studies based on multidisciplinarity, interdisciplinarity, and transdisciplinarity (1), the Gantt chart of upcoming activities (2), and evaluation criteria for the TDR project (3)
	2.3. TDR conceptual framework development and refinement (8, 9, 10)	2.3.1. A TDR framework for the project on which the team will collaborate
3. Transdisciplinary knowledge exchange	3.1. HEIs and wider public engagement (1, 2, 3)	3.1.1. Summary of the outcomes of engagement with the public (1) and a summary of the outcome of engagement with HEIs (2)
	3.2. Transdisciplinary knowledge integration (4, 5, 6)	3.2.1. A diagram showing hierarchical levels of transdisciplinarity of the TDR project (1), systematic reviews of related work (2), and co-authored draft papers for TDR dissemination (3)
	3.3. TDR dissemination and training for academic and non-academic community members (7, 8, 9)	3.3.1. Training and development plan (1), summative evaluation criteria (2), and summative evaluation of transdisciplinary knowledge exchange processes (3)

5. Validation of a General Framework for Conducting TDR

5.1. Introduction

The validation of the proposed general framework for TDR was undertaken by engaging with academics and industry professionals globally. Their views were sought regarding the clarity of the logic behind the proposed actions, associated stages, and the three phases (TDR initiation, TDR management, and transdisciplinary knowledge exchange). The additional aim was to investigate whether each action was considered important or not to refine the proposed general framework for transdisciplinary research.

The survey participants included academic staff from the Faculty of Engineering and the Faculty of Science at the University of Strathclyde, Glasgow (Glasgow, UK), Lancaster University (Lancaster, UK), the University of Wolverhampton (Wolverhampton, UK), Cornell University (Ithaca, NY, USA), the University of Oregon (Eugene, OR, USA), the University of Management and Technology (Lahore, Pakistan), the Norwegian University of Science and Technology (Trondheim, Norway), Queensland University of Technology (Brisbane, Australia), and University Sains Malaysia (Gelugor, Penang, Malaysia). The industry participants were professionals who were chartered members and fellows of the Royal Institute of British Architects (RIBA), the Royal Institute of Chartered Surveyors (RICS), and the Pakistan Council of Architects and Town Planners (PCATP).

The survey results showed that the academics and industry professionals agreed with most of the proposed actions as part of the general framework for transdisciplinary research. However, a few actions were considered unimportant by the study participants.

The validation of the proposed general framework for transdisciplinary research had a few limitations. Initially, the recorded presentation would have been followed by online interviews, but due to the high response rate and international research participants, the research method was modified to an online questionnaire. Section 5.2 discusses how the survey participants were engaged and selected and the inclusion criteria for academics and industry professionals. Section 5.3 describes the study results based on the questions of the online survey and presents justifications regarding its application in academia or industry from the perspectives of researchers and industry professionals.

5.2. Survey Participants

While the proposal for the general framework for transdisciplinary research was being finalized; a LinkedIn poll was set up to discover prospective research participants from a list of nearly 5000 followers. The LinkedIn poll presented a brief definition of TDR as it brings together various disciplines to work jointly to create new conceptual, theoretical, and methodological innovations moving beyond discipline-specific approaches to address a common problem.

The question statement of the poll was whether an academic or industry professional is interested in contributing to a framework associated with transdisciplinary research. The poll options included: (1) I am interested and (2) I want to know more. The LinkedIn poll was viewed by over 3500 academics/industry professionals. 68% of the viewers indicated that they were interested, whereas 32% wanted to know more.

For the interested academics and industry professionals (n = 15), a recorded online presentation was prepared on Zoom, providing a brief overview of the research and the proposed three phases, associated stages, and related actions of a general framework for transdisciplinary research. An online questionnaire (Appendix A) related to the TDR framework was developed, which questioned the importance of actions in each associated stage in each phase. The online questionnaire also investigated whether the prospective participants were involved in TDR before or whether they intend to undertake TDR in the future. The survey also questioned if the study participants thought that the actions of each phase were logical, in which areas of practice or industry a particular action/associated stage/phase may be applicable, and any possible suggestions or recommendations related to the research.

The inclusion criterion for academics and industry professionals was established. The inclusion criterion for an academic was that the academic needs to be a member of staff of a degree-awarding HEI. The inclusion criterion for industry professionals was that the individual needs to be a member or a fellow of a professional accreditation body. The recorded online presentation, consent form, participant information form, and online questionnaire were shared with selected researchers and industry professionals from various disciplines, universities, and chartered accreditation bodies.

5.3. Survey Results

A total of 86.7% of the respondents identified themselves as academics/researchers/scientists, whereas 13.3% of the study participants were industry professionals (engineers, architects, or designers). 80% of the study participants had conducted TDR, while 20% had not taken part in TDR before. A total of 86.7% of the study participants expressed their interest and that they aim to conduct TDR, whereas 13.3% anticipated that they do not aim to do so. Tables 2–4 show the phases of a general framework for conducting TDR, its associated stages, related actions, and the positive and negative responses identified by the survey participants.

Table 2. TDR Initiation, associated stages, actions, and survey results.

Validation of a General Framework for Conducting TDR				
TDR Phase	**Associated Stage**	**Action**	**Positive Response**	**Negative Response**
1. TDR initiation	1.1. Skills development	1.1.1. Exploratory phase of collective thinking, the hierarchy of needs, constructivism, and organisational learning [18]	80%	20%
		1.1.2. Collaborative learning environments and thinking skills; communication and empathy skills [17,24,27,32]	93%	7%
		1.1.3. Workshops on interdisciplinary research, areas of responsible research conduct, and mentor–mentee relationship [22]	80%	20%
	1.2. Context and stakeholder identification	1.2.1. Transdisciplinary framework—context and setting in which transdisciplinary collaboration is taking place [28]	73%	27%
		1.2.2. Problem identification, problem relevance, connectivity, roles and responsibility, interests and concerns, and collaboration culture [29,31]	93%	7%
		1.2.3. Stakeholder mapping, scope definition, strategic impact mapping, and roadmap definition; methods of categorising participants [34,35]	93%	7%
		1.2.4. Combination types of scientists for a high-performing team; tie strength, perceived trustworthiness, and receipt of beneficial knowledge [16,21]	80%	20%
	1.3. Problematisation	1.3.1. Creating a common ground; common language that can be used in various disciplines by environmental managers and within global markets [19,25]	80%	20%
		1.3.2. Co-design; joint problem formulation; and project design [20,23,30]	93%	7%
		1.3.3. Participatory planning, boundary management, and conflict mediation utilising ICT tools [26,33]	80%	20%

Table 3. TDR management, associated stages, actions, and survey results.

Validation of a General Framework for Conducting TDR				
TDR Phase	**Associated Stage**	**Action**	**Positive Response**	**Negative Response**
2. TDR management	2.1. Transdisciplinary boundary management and TDR problem dimensions	2.1.1. Managing differences that may damage partnerships, decision-making regarding collaboration, understanding collaborative forces, and classification of essential supporters [36]	80%	20%
		2.1.2. Demarcating boundaries to problems for analysing and solving them; scientific dimension, international dimension, and sectoral dimension [20,37]	73%	27%
		2.1.3. Categorising participants based on levels of collaboration and levels of integration and stakeholder alignment [33–35]	75%	25%
	2.2. TDR project co-planning and co-management	2.2.1. Transdisciplinary co-learning framework—the process encompasses the cooperation being implemented, organised, and managed [28]	80%	20%
		2.2.2. Identifying case studies to review history and analysing institutions, policies, and governance to measure and compare their ecological, economic, social, and cultural sustainability dimensions [38]	80%	20%
		2.2.3. Project planning and management—conception, implementation, and evaluation of agendas, social experiments, research, synergy, and unifying various partnership activities [40]	100%	0%
		2.2.4. Project evaluation—formative evaluation of process and impacts; co-management—implementation, management, and evaluation of a TDR/NBS project [23,44]	80%	20%
	2.3. TDR conceptual framework development and refinement	2.3.1. Utilising all opportunities when researchers from different disciplines meet to refine conceptual frameworks, forming IDR teams to proactively pursue the identification and integration of all scientific disciplines in the TDR project by mapping the contribution of each discipline [41]	66%	34%
		2.3.2. Collaborative research methods and education in informal learning environments; collaboration network of HEIs and regional stakeholders [24,39]	60%	40%
		2.3.3. Preliminary analysis, round table discussion or by email, complete analysis; quantification and comparison of benefits/costs for preferred alternatives, implementation, and adaptive management [42,43]	60%	40%

Eighty percent of all academics and industry professionals expressed that all actions and associated stages of the three phases (TDR initiation, TDR management, and transdisciplinary knowledge exchange) were logical. The remaining 20% mentioned that there are some actions/activities of the proposed general framework for transdisciplinary research that should not be actioned or planned and be left to spontaneity as instilling values is more important than instilling structured activities. The survey questioned study participants regarding any possible amendments for each phase of the framework for transdisciplinary research, e.g., a change in the order. The respondents agreed that there should be no changes or amendments to any of the phases of the framework for transdisciplinary research; however, two academics believed that the framework might be too complex for industry and practice.

Table 4. Transdisciplinary knowledge exchange, associated stages, actions, and survey results.

Validation of a General Framework for Conducting TDR				
TDR Phase	**Associated Stage**	**Action**	**Positive Response**	**Negative Response**
3. Transdisciplinary knowledge exchange	3.1. HEIs and wider public engagement	3.1.1. Nurturing stakeholder relations and community consensus and implementing various social experiments; the role of intermediaries facilitating, convening, and mediating the relationships [40,52]	80%	20%
		3.1.2. Knowledge interfacing and sharing; balancing practical applicability with theoretical progress, giving formal introductions to other research fields, and further developing institutional support for integrative Ph.D. projects [45,46]	87%	13%
		3.1.3. Developing IDR/TDR ethical and value system for collaborative engagement within the research team; highly connected knowledge networks; institutional access to funding, material, experimental, and technological resources [47]	67%	33%
	3.2. Transdisciplinary knowledge integration	3.2.1. Interactions between art and the humanities, the research base in higher education, and cultural and creative industries; formal and informal knowledge transfer processes [49,53]	87%	13%
		3.2.2. Transdisciplinary knowledge integration processes—co-production processes that bring together different knowledge types across the science–society interface [55]	93%	7%
		3.2.3. Transdisciplinary co-learning framework to subsume intended and unintended outputs, effects, outcomes, and impacts [28]	93%	7%
	3.3. TDR dissemination and training for academic and non-academic community members	3.3.1. An increased diversity of knowledge areas needs to be combined to solve complex societal problems by training specialists with specific skills in collaborative interactions at a high abstraction level [48]	93%	7%
		3.3.2. Academic and non-academic urban knowledge producers—residents, activists, practitioners, experts, researchers, and policymakers [50]	93%	7%
		3.3.3. The transferability of community-owned solutions between native communities and achievements of community peer-to-peer knowledge; formative and summative evaluation of knowledge transfer processes [51,54]	80%	20%

6. Discussion

The identified studies from the literature review were used to develop a general framework for conducting TDR. The studies were categorized relating to TDR initiation, TDR management, and transdisciplinary knowledge exchange. This categorization led

to the three phases of a general framework for conducting TDR and its testing through a survey.

The survey identified that 86.7% of the study participants aimed to conduct TDR, whereas 13.3% anticipated not to. The increase in the percentage (6.7%) of participants who had already conducted TDR (80%) compared to the participants who aim to do so in the future (86.7%) evidenced the awareness, willingness, and belief that the study participants have in TDR to resolve complex societal problems for a more sustainable future.

In relation to TDR initiation, the strongest agreement by academics and industry professionals was with the second, fifth, sixth, and ninth actions entailing collaborative learning environments, thinking skills, communication, and empathy skills; problem identification, problem relevance, connectivity, roles, and responsibility, interests, and concerns, and collaboration culture; stakeholder mapping, scope definition, strategic impact mapping, and roadmap definition; methods of categorising participants; and co-design; joint problem formulation, and project design, respectively. An unexpected finding regarding TDR initiation and its eighth action (creating a common ground; a common language that can be used in various disciplines by environmental managers and within global markets) was that 20% of all the survey participants who disagreed with the action's importance were academics. Regarding TDR management, all the academics and industry professionals agreed that project planning and management entailing conception, implementation, and evaluation of agendas, social experiments, research, synergy, and unifying various partnership activities is required for TDR project co-planning and co-management. Several actions (the fifth, sixth, seventh, and eighth) had strong agreements relating to transdisciplinary knowledge exchange. These actions related to transdisciplinary knowledge integration processes—co-production processes that bring together different knowledge types across the science–society interface; the transdisciplinary co-learning framework to subsume intended and unintended outputs, effects, outcomes and impacts; increased diversity of knowledge areas need to be combined to solve complex societal problems by training specialists with specific skills in collaborative interactions at a high abstraction level; and academic and non-academic urban knowledge producers (residents, activists, practitioners, experts, researchers, and policymakers). An outlier was the view of an industry professional who believed that the fifth, sixth, and seventh actions of transdisciplinary knowledge exchange are insignificant for the general framework for conducting TDR.

The academics believed that the framework would be beneficial in the design of buildings where many professionals work in silos because it would enable collaboration of various professions, such as architects and engineers, at early stages to reduce the carbon footprint and its impacts. The academics mentioned that the framework could also influence academia as learning environments need to change to reflect the new needs of transdisciplinary practices required by future professionals, and community engagement on projects at urban levels will strengthen transdisciplinary practice-based frameworks. The academics believed that the general framework for TDR is applicable in urban planning and management and that the academic and non-academic urban knowledge producers are highly important. The participating academics emphasised that the general TDR framework would facilitate collaboration between spatial planners, humanitarian actors, and decision-makers in relation to short- and long-term responses to unexpected environmental crises. They indicated that the framework for TDR is appropriate in architectural design practice in the initial stages of the design process including pre-design, advanced planning, and programme and project brief development. They believed that the framework could be applied in numerous research communities and industry sectors, such as the sustainable use of packaging materials, conceptual and design development, and multisectoral research projects related to design, architecture, and public health. The participating industry professionals believed that the most interesting aspect of the general framework for TDR was TDR dissemination to the wider community and the exploration of possible innovation and knowledge exchange as wider public engagement outside academia may help to initiate and activate a response that would truly benefit multiple stakeholders. The presented

framework for conducting TDR has been validated (Figure 4) based on the responses of academics and industry professionals.

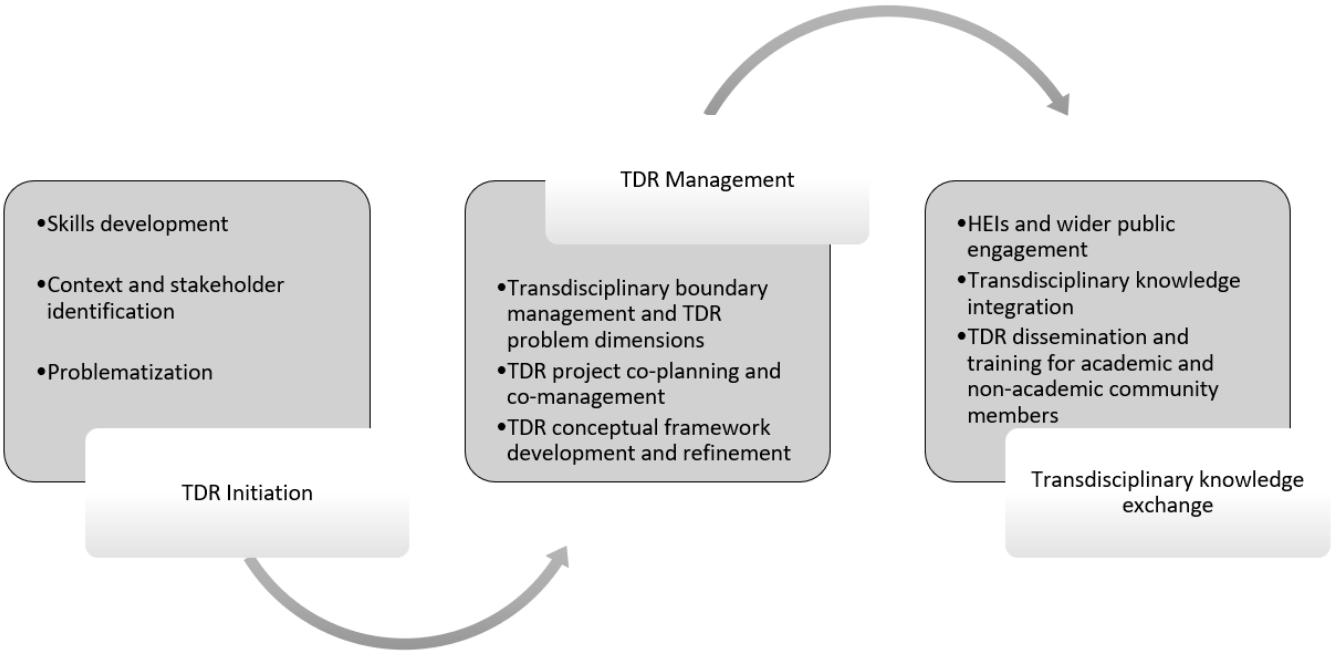

Figure 4. Validated general framework for conducting TDR.

Comparison with Other Frameworks for Conducting TDR

Transdisciplinarity aims to integrate disciplinary fragmented knowledge [57]. This has led to the creation of a variety of frameworks for conducting TDR for sustainable development [58]. This subsection compares the validated general framework for conducting TDR with previously conceptualised frameworks for conducting TDR to highlight the novelty of the undertaken research. Tejada et al. [58] presented a phased framework with design principles for ideal TDR; however, there was not enough emphasis on TDR management. There are other frameworks, which focus on certain parts of the validated general framework, such as Muhar and Penker's [59] framework for transdisciplinary knowledge exchange. Their framework focused on who can contribute what kind of knowledge in which phase of a transdisciplinary project and why. Fazey's [60] ten processes for transformational change and their simultaneous application can create an adaptive, reflexive, collaborative, and impact-oriented form of research to enable knowledge integration. Potential further research related to the validated general framework is needed to investigate whether there are actions in each associated stage, which can run simultaneously. Potential further research will also advance what was proposed by Brandt et al. [12] to identify how other TCFs can be classified to contribute to various phases for conducting TDR. The dataset in their paper [12] identified 236 studies, which encompassed calls for TDR, the development of methods, and the application of methods. From that dataset [12], 132 studies did not apply TDR, and the remaining 104 studies were case studies where TDR has been applied. Future research will explore whether any of those case studies were related to sustainable buildings. Brandt et al. [12] also identified five central issues that can be explored in future research to map for TDR initiation, TDR management, and transdisciplinary knowledge exchange.

7. Conclusions

The paper aimed to explore TCFs that support knowledge transfer within academia and with industry and develop and test a general framework for conducting TDR. The systematic literature review enabled the discovery of influential themes which were TDR initiation, TDR management, and transdisciplinary knowledge exchange. Studies from these themes helped the development, systematisation, and testing of a general framework

for conducting TDR. The recorded presentation and an online questionnaire provided initial confirmation of the validity of the framework for conducting TDR. The systematic literature review and the validation of the proposed general TDR framework with academics and industry professionals showed how increased communication between disciplines can help in addressing complex societal problems such as sustainable development, global environmental change, and unexpected environmental crises. Potential further research may entail including more participants or using other research methods, e.g., a workshop or a conference. The research findings provide a foundation for developing a TCF for NBD of sustainable buildings aligned with the RIBA Plan of Work.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (Ethics Committee) of the University of Strathclyde (Details of protocol available at: https://www.strath.ac.uk/ethics/, accessed on 10 December 2022). The date of approval is available on request.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are not available as the permissions for public availability of responses were not given by the survey respondents.

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

Appendix A. Online Questionnaire for the Proposed General Framework for TDR

A Framework for Transdisciplinary Research

Thank you very much for expressing your interest in participating in my Ph.D. research via LinkedIn or email.

My name is Anosh Nadeem Butt, and I am a Ph.D. Student and PGR Representative working under the supervision of Professor Branka Dimitrijević at the Department of Architecture, Faculty of Engineering, University of Strathclyde, Glasgow, UK.

My email address is anosh.butt.2018@uni.strath.ac.uk.

My research aims to explore multidisciplinary approaches to the design of sustainable buildings and aims to develop and test a transdisciplinary collaboration framework for the nature-based design of the sustainable built environment (SBE). The first step in achieving this goal is to develop a general framework for transdisciplinary research.

Transdisciplinary research brings together various disciplines to work jointly to create new conceptual, theoretical, and methodological innovations moving beyond discipline-specific approaches to address a common problem.

Initially, the recorded presentation would have been followed by interviews, but due to the large response rate and international research participants, the research method had to be modified to an online questionnaire.

Below are a few questions based on an initial framework for conducting transdisciplinary research. Your feedback (e.g., questions and suggestions) will help to refine it.

1. How do you identify yourself professionally?

☐ Academic/Researcher/Scientist

☐ Industry Professional (Engineer/Architect/Designer)

2. Have you conducted transdisciplinary research before?

☐ Yes
☐ No

3. Do you plan to undertake transdisciplinary research?

☐ Yes
☐ No

4. TDR Initiation

How essential are the following actions for TDR initiation (skills development)?

Action	Not Important at All	Somewhat Important	Important	Very Important
1. Exploratory phase of collective thinking, hierarchy of needs, constructivism, and organisational learning	☐	☐	☐	☐
2. Collaborative learning environments and thinking skills; communication and empathy skills	☐	☐	☐	☐
3. Workshops on interdisciplinary research, areas of responsible research conduct, and mentor–mentee relationship	☐	☐	☐	☐

How essential are the following actions for TDR initiation (context and stakeholder identification)?

Action	Not Important at All	Somewhat Important	Important	Very Important
4. Transdisciplinary co-learning framework—context (the setting in which transdisciplinary collaboration is taking place)	☐	☐	☐	☐
5. Problem identification, problem relevance, connectivity, roles and responsibility, interests and concerns, and collaboration culture	☐	☐	☐	☐
6. Stakeholder mapping, scope definition, strategic impact mapping, and roadmap definition; methods of categorising participants	☐	☐	☐	☐
7. Combination types of scientists for a high-performing team; tie strength, perceived trustworthiness, and receipt of beneficial knowledge	☐	☐	☐	☐

How essential are the following actions for TDR initiation (problematisation)?

Action	Not Important at All	Somewhat Important	Important	Very Important
8. Creating a common ground; common language that can be used in various disciplines by environmental managers and within global markets	☐	☐	☐	☐
9. Co-design; joint problem formulation and project design	☐	☐	☐	☐
10. Participatory planning, boundary management, and conflict mediation utilising ICT tools	☐	☐	☐	☐

5. TDR Management

How essential are the following actions for TDR management (transdisciplinary boundary management and TDR problem dimensions)?

Action	Not Important at All	Somewhat Important	Important	Very Important
1. Managing differences that may damage partnerships, decision-making regarding collaboration, understanding collaborative forces, and classification of essential supporters	☐	☐	☐	☐
2. Demarcating boundaries to problems for analysing and solving them; scientific dimension, international dimension, and sectoral dimension	☐	☐	☐	☐
3. Categorising participants based on levels of collaboration and levels of integration, and stakeholder alignment	☐	☐	☐	☐

How essential are the following actions for TDR management (TDR project co-planning and co-management)?

Action	Not Important at All	Somewhat Important	Important	Very Important
4. Transdisciplinary co-learning framework—process (encompasses the cooperation being implemented, organised, and managed)	☐	☐	☐	☐
5. Identifying case studies to review history, analysing institutions, policies, and governance to measure and compare their ecological, economic, social, and cultural sustainability dimensions	☐	☐	☐	☐
6. Project planning and management—conception, implementation, and evaluation of agendas, social experiments, research, synergy, and unifying various partnership activities	☐	☐	☐	☐
7. Project evaluation—formative evaluation of process and impacts; co-management—implementation, management, and evaluation of an TDR/NBS project	☐	☐	☐	☐

How essential are the following actions for TDR management (TDR conceptual framework development and refinement)?

Action	Not Important at All	Somewhat Important	Important	Very Important
8. Utilising all opportunities when researchers from different disciplines meet to refine conceptual frameworks, forming IDR teams to proactively pursue the identification and integration of all scientific disciplines in the TDR project by mapping the contribution of each discipline	☐	☐	☐	☐
9. Collaborative research methods and education in informal learning environments; collaboration network of HEIs and regional stakeholders	☐	☐	☐	☐
10. Preliminary analysis, round table discussion or by email, complete analysis; quantification and comparison of benefits/costs for preferred alternatives, implementation, and adaptive management	☐	☐	☐	☐

6. Transdisciplinary knowledge exchange

How essential are the following actions for transdisciplinary knowledge exchange (HEIs and wider public engagement)?

Action	Not Important at All	Somewhat Important	Important	Very Important
1. Nurturing stakeholder relations and community consensus and implementing various social experiments; the role of intermediaries, facilitating, convening, and mediating the relationships	☐	☐	☐	☐
2. Knowledge interfacing and sharing; balancing practical applicability with theoretical progress, giving formal introductions to other research fields, and further developing institutional support for integrative Ph.D. projects	☐	☐	☐	☐
3. Developing an IDR/TDR ethical and value system for collaborative engagement within the research team; highly connected knowledge networks; institutional access to funding, material, experimental, and technological resources	☐	☐	☐	☐

How essential are the following actions for transdisciplinary knowledge exchange (transdisciplinary knowledge integration)?

Action	Not Important at All	Somewhat Important	Important	Very Important
4. Interactions between art and the humanities, research base in higher education, and cultural and creative industries; formal and informal knowledge transfer processes	☐	☐	☐	☐
5. Transdisciplinary knowledge integration processes (co-production processes that bring together different knowledge types across the science–society interface)	☐	☐	☐	☐
6. Transdisciplinary co-learning framework—outcomes (subsumes intended and unintended outputs, effects, outcomes, and impacts)	☐	☐	☐	☐

How essential are the following actions for transdisciplinary knowledge exchange (TDR dissemination and training for academic and non-academic community members)?

Action	Not Important at All	Somewhat Important	Important	Very Important
7. Increased diversity of knowledge areas needs to be combined to solve complex societal problems by training specialists with specific skills in collaborative interactions at a high abstraction level	☐	☐	☐	☐
8. Academic and non-academic urban knowledge producers (residents, activists, practitioners, experts, researchers, and policymakers)	☐	☐	☐	☐
9. The transferability of community-owned solutions between native communities and achievements of community peer-to-peer knowledge; formative and summative evaluation of knowledge transfer processes	☐	☐	☐	☐

7. Are the actions of each phase logical?

☐ Yes
☐ No
If no, what modifications do you suggest and why?

_____

_____

8. What would be any possible amendments for each phase of the framework for transdisciplinary research, e.g., change in order?

☐ Yes
☐ No
If yes, which actions need to change?

_____

_____

9. In which areas of practice or industry do you see a certain action/associated stage/phase applicable?

_____

_____

10. Please feel free to raise any questions that you might have in relation to the presentation of the research undertaken to date or to provide suggestions or recommendations.

_____

_____

11. The survey results will be included in a journal paper that is being prepared. Please indicate if you would like to receive information on the published paper.

☐ Yes
☐ No
Thank you for completing the questionnaire.

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