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A Transdisciplinary Overlay for Nature-Based Design of Sustainable Buildings

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Abstract: The article presents the development and validation of transdisciplinary collaboration (TDC) guidelines for nature-based design (NBD) of sustainable buildings that were used to develop and validate a proposed NBD Overlay of the Royal Institute of British Architects (RIBA) Plan of Work (PoW) 2020. The study first presents the results of consultations with architects on the application of NBD in all stages the RIBA PoW. The development of the proposed NBD Overlay of the RIBA PoW is described, followed by the results of a survey of architects on its contents. Over 80% of the architects in the consultation group confirmed the significance of the proposed NBD Overlay and its relevance in advancing sustainable building practices. The potential of the proposed NBD Overlay to foster tansdisciplinary collaboration and promote NBD approaches, principles, and solutions bodes well for the future of sustainable architecture, driving the industry towards a more resilient and environmentally conscious built environment.

Keywords: BREEAM; nature-based design; RIBA plan of work; sustainability; sustainable buildings; transdisciplinary collaboration

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1. Introduction

Sustainable development occupies a crucial position in global discourse since 1990s, and architects, designers, engineers, clients, and decision-makers have been addressing the environmental dimensions of sustainable building design to tackle the ambiguities resulting from the incomplete understanding of the problems associated with the environment [1]. Architectural design must respond to environmental, social, and economic sustainability challenges by aligning numerous stakeholders together and working on various scales [1]. The overarching aim of the research is to support application of nature-based design (NBD) in architectural practice to achieve the above goals while providing enhanced user experiences and improved well-being. Motivation for focusing on NBD in architectural design and engineering solutions is in the opportunity to develop new knowledge on properties and performance of biomaterials and on characteristics of biostructures and bioprocesses that achieve goals common to architectural and engineering designs, such development of materials, processes, and designs that result in structural strength, durability, adaptability, absence of waste, possibility of reuse or recycling, pleasing aesthetics, and life-supporting conditions.

NBD research to date has focused on its application in building context [2], inspiration from natural forms (biomorphism) [3–7] and processes (biomimicry) [8–11], building materials [12–16], structural efficiency [17,18], building envelope [14,16,19,20], building services for health and well-being of occupants [8,12,15,21,22], and on other strategies and solutions for improving occupants' health and well-being [13,23–25].

Transdisciplinary research (TDR) produces knowledge that goes beyond the existing disciplines [26,27] and often draws from and contributes to what is called *interdisciplines*, which are hybrid fields that emerge around particular issues, e.g., sustainability science [28–30]. Transdisciplinary collaboration (TDC) is completely integrated [31,32], as it combines more disciplinary contributions from different disciplines to generate a comprehensive level of understanding by developing systemic frameworks of several disciplinary and interdisciplinary contributions [33,34]. A transdisciplinary collaboration framework (TCF) enables knowledge production due to the combination of scientific expertise developed through various insights in respective disciplines [35].

The understanding of possible applications of biomaterials and processes in building design requires transdisciplinary collaboration (TDC) of biologists and environmentalists with architects, engineers, and public stakeholders. Preceding studies [35,36] revealed a lack of a transdisciplinary collaboration framework (TCF) for implementing NBD in building design and proposed a general TCF that identifies phases for developing and managing TDC, including related tools. The proposed general TCF is flexible in terms of its applicability in different areas of TDC.

The overlays to the RIBA Plan of Work are intended as professional guidance in certain focus areas relative to the stages of work. These Overlays include: the BIM Overlay [37]; the Design for Manufacture and Assembly (DfMA) Overlay [38]; the Engagement Overlay [39]; the Green Overlay [40]; the Inclusive Design Overlay [41]; the Passivhaus Overlay [42]; the Security Overlay [43]; and the Smart Building Overlay [44]. To demonstrate how TDC can be planned and managed throughout building design process, the study proposes an NBD Overlay of the Royal Institute of British Architects (RIBA) Plan of Work (PoW) 2020. The RIBA PoW allows for organising the processes of briefing, designing, constructing, and operating building projects into eight stages and explains stage outcomes, core tasks, and information exchanges needed at each stage [45]. The study shows that project architects who designed Outstanding buildings in the UK, rated by using the Building Research Establishment Environmental Assessment Methodology (BREEAM), applied NBD at various stages of the RIBA PoW.

The proposed NBD Overlay of the RIBA PoW, comprising guidelines for TDC on the NBD of sustainable buildings, is a novel contribution of this article that builds on the previously developed and validated general TCF [35]. Its primary target audience and beneficiaries are architects who apply the RIBA PoW in building design practice as the NBD Overlay guidelines indicate how TDC can be initiated and managed and what knowledge management methods might be used to record and share the collaboration outputs during the development of building design and for future reference. The NBD Overlay should be considered as guidelines that can be adapted to the existing project management procedures which might vary in different architectural practices. Academics can use the NBD Overlay in further studies on TDC in planning and management of architectural projects and on possibilities for application of NBD in civil engineering design and infrastructure projects by adapting the guidelines to the related project management practices. The NBD Overlay of the RIBA PoW demonstrates how theories on TDC can be developed as practical guidelines for application of NBD in architecture and potentially in other types of engineering projects.

The focus of Section 2 is on materials and methods. Section 3 includes a survey on the engagement of architects in NBD within the RIBA PoW stages. Sections 4 and 5 present an NBD Overlay to the RIBA PoW 2020, including the guidelines for TDC and its validation. The research findings are presented and discussed in Sections 6 and 7, respectively, while Section 8 provides the conclusions and recommendations for future research.

2. Materials and Methods

For the survey on the engagement of architects in NBD, 120 projects [46] built in the UK that had received a BREEAM Outstanding rating were identified in the Building Research Establishment's (BRE's) database [47].

The next step included identifying architects and designers of these projects using the websites of the related architectural firms. If the architects involved in the above projects changed their workplaces, LinkedIn was used to identify where they work. For the 120 BREEAM Outstanding-rated projects, 120 bespoke online surveys [46] were prepared and shared with the respective firms to be forwarded to the project architects. The survey questions [48] explored (1) at what stage of the RIBA PoW the project architect utilised an NBD approach; (2) which BREEAM categories were considered in relation to the implementation of NBD solutions; and (3) the professional background of the staff who collaborated on NBD for improving the sustainability of buildings. A total of 27 responses to the survey were received.

Existing RIBA PoW Overlays [37–44,49] were studied to understand how to adapt and integrate the previously validated general framework for conducting TDR [35] into the RIBA PoW 2020.

The findings of the survey of project architects (n = 27) who responded to the survey [48] on the application of NBD in their BREEAM Outstanding projects were used to propose at what stages of the RIBA PoW 2020 the application of NBD should be planned, accompanied by a description of related TDC and of possible knowledge management methods.

The proposed NBD Overlay of RIBA PoW 2020 was validated through an online survey [50] of project architects of their BREEAM Outstanding projects and other RIBA Chartered Architects who responded (n = 16) to the survey.

3. Survey on the Engagement of Architects for NBD Applications at Different Stages of the RIBA PoW in BREEAM Outstanding Projects

The survey aimed to explore if NBD was applied in BREEAM Outstanding projects in the UK [48]. BREEAM is selected for this research because of its wide assessment scope (buildings of different typologies, communities) and its high level of application (200,000 buildings with BREEAM assessment ratings and over two million registered for assessment since it was launched in 1990) [51]. BREEAM measures building performance against established benchmarks to evaluate a building's specification, design, construction, and use. Building performance is measured in relation to the following categories: energy, health and well-being, innovation, land use, materials, management, pollution, transport, waste, water, resources, and resilience.

BREEAM assessment criteria do not specifically mention nature-based solutions NBSs). However, NBSs are relevant to achieving BREEAM certification as they align directly with various categories and criteria focused on environmental sustainability. If included as one of the criteria in BREEAM's "*Land Use and Ecology*" category, NBSs would contribute to the protection, restoration, and enhancement of natural habitats and ecosystems. Strategies such as biophilia could incorporate green roofs and walls, using native plants in landscaping, and preserving existing ecological features to enhance biodiversity and improve ecological outcomes, which are essential for meeting BREEAM objectives in this area.

Additionally, NBSs contribute to the "*Health and Wellbeing*" category by enhancing indoor and outdoor environments. For instance, green spaces and biophilic design elements improve air quality, reduce urban heat island effects, and provide aesthetic and psychological benefits to building occupants.

Similarly, in the "*Water*" category, building elements like rain gardens, permeable pavements, and wetland systems help manage stormwater sustainably, reducing flooding risks and enhancing water quality.

NBSs support BREEAM's overarching goals by incorporating climate adaptation measures, improving resource efficiency, and promoting sustainable building design. These solutions may help achieve higher BREEAM ratings but also align with broader environmental goals by fostering resilience and ecosystem preservation and regeneration.

The study participants for the survey included project architects (Chartered Members of the RIBA) and design teams involved in the NBD of BREEAM Outstanding projects. At the time of investigation 120 BREEAM Outstanding-rated projects were identified from the BRE's Database [46]. Bespoke online surveys [46,48] were sent to the respective firms to be forwarded to the project architects. A total of 27 responses were received and analysed [52].

3.1. Survey Results

The response data include information on related clients, the BREEAM scheme rating scores, and the buildings' locations [46].

Figure 1 presents the **functions of the 27 buildings** for which survey responses were received: 33% are fire stations, 30% are offices, 11% are buildings in higher education institutions (HEIs), 7% are retail and commercial projects, and the remaining 19% of the projects are related to other building types such as business parks, multi-residential buildings, refurbishment and fit-out projects, campuses, and libraries.

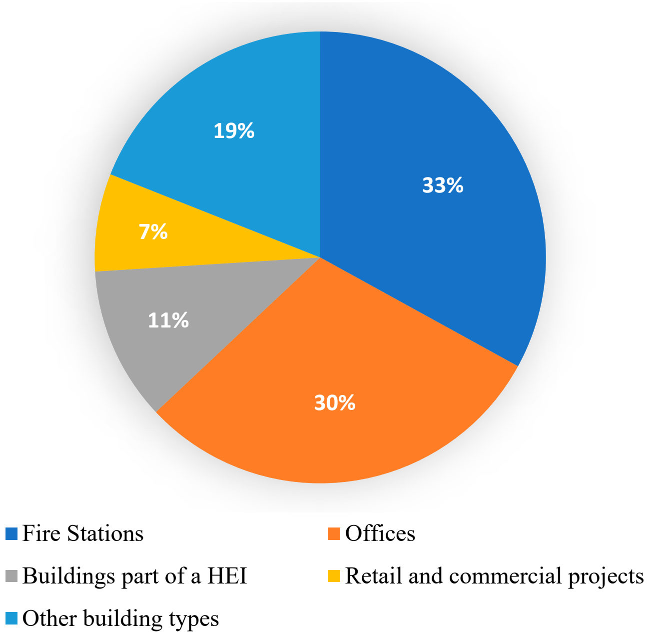

Figure 1. Functions of the BREEAM Outstanding buildings that were part of the survey results.

It is necessary to understand and identify any prevalent design philosophies within related architectural firms that may have influenced the application of NBD approaches for the design of BREEAM Outstanding rated projects.

A third of the surveyed BREEAM Outstanding rated projects ($n = 9$) were designed by BDP. One of BDP's values is to be creative, and they clarify that the architectural firm is curious by nature and includes thought leaders, innovators, and early adopters of new technologies [53]. Furthermore, BDP promotes interdisciplinary collaboration, encouraging professions from diverse backgrounds to deliver innovation collectively [53]. The case study reveals various trends and motivations of clients and developers who are key stakeholders in the design process and the application of NBD approaches.

Fire stations in London were developed by Blue3 (a consortium comprising Kier and DIF Infrastructure II), while others, including The Featherstone Building, London, designed by Morris + Company and White Collar Factory, London, designed by Allford Hall Monaghan Morris, had Derwent London as their client. Blue3 demonstrates a strong passion for innovation and embraces the incorporation of new technologies and processes, along with staying updated on developments in legislation and sustainability requirements [54]. Additionally, as a fully integrated infrastructure provider, Blue3 actively embraces new technologies to enhance environmental performance [54]. Derwent London emphasizes that sustainability is deeply rooted in their business ethos, emphasizing the importance of reusing as much of the original fabric as possible, which aligns with both their financial objectives, and environmental goals. As part of their commitment to lead the industry in climate change mitigation, Derwent London has set a goal to achieve net-zero carbon status by 2030 [55].

While 33% of the projects in the sample are fire stations, it is important to clarify that although this may create the appearance of a skewed sample, it reflects a specific trend in NBD implementation for certain project types, particularly fire stations. This trend does not imply that NBD is applied exclusively at a certain stage for a particular building function or that its importance in the design stages is diminished. Rather, NBD is applied flexibly across various stages depending on the building type and project goals.

RIBA PoW stages in which NBD was used were as follows: in fire stations at Stage 0; in all office buildings (30% of the total respondents) at the initial Stages 0–2, except for The Catalyst, Newcastle University (Stages 1–5) and 1 Pancras Square, London (Stages 0–7). Application of NBD in HEI buildings varied from none in one building, at Stage 1 in another one, and at Stages 0–7 in the third one. BREEAM Outstanding-rated projects associated with Higher Education Institutions (HEIs) showed varied responses regarding the application of NBD approaches and stages of the RIBA PoW. Some project architects mentioned applying NBD approaches at Stage 1 (GlaxoSmithKline Carbon Neutral Laboratories for Sustainable Chemistry, the University of Nottingham by Fairhursts Design Group); while others adopted a more holistic approach, applying across all stages of the RIBA PoW (Edinburgh Centre for Carbon Innovation, the University of Edinburgh by Malcolm Fraser Architects). Some specified that NBD approaches were not necessary for their building designs (the Saw Swee Hock Student Centre, the London School of Economics by O'Donnell + Tuomey Architects).

3.1.1. Application of NBD Approaches and Stages of RIBA Plan of Work

Figure 2 shows that the application of NBD was most common at Stage 0: Strategic Definition (23%); followed by Stage 1: Preparation and Briefing (18%); Stage 2: Concept Design (18%); Stage 3: Spatial Coordination (11%); Stage 4: Technical Design (11%); Stage 5: Manufacturing and Construction (9%); Stage 6: Handover (5%); and Stage 7: Use (5%). The project architects of all the BREEAM Outstanding rated projects emphasized the highest utilization of NBD approaches at Stage 0: Strategic Definition; followed by Stage 1: Preparation and Briefing, and Stage 2: Concept Design. As stages progressed, the extent of NBD approach application decreased from Stage 3: Spatial Coordination, and Stage 4: Technical Design; to Stage 5: Manufacturing and Construction; to Stage 6: Handover and Stage 7: Use. The collected responses of the project architects reveal that the extent of the application of NBD approaches decreases from Stage 0 to Stage 7.

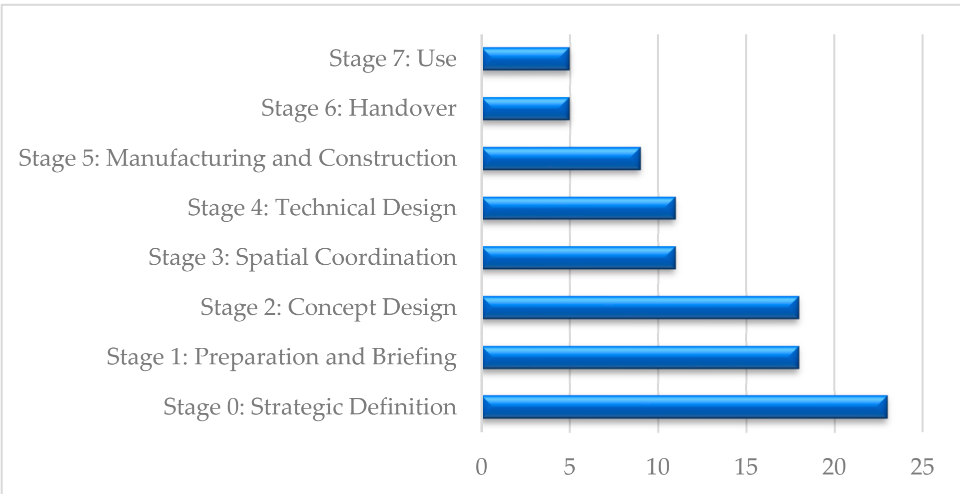

Figure 2. Percentage of application of NBD within the stages of the RIBA PoW.

A part of the total respondents, which included project architects from David Chipperfield Architects and Malcolm Fraser Architects, mentioned that they applied an NBD approach in all stages of the RIBA PoW for the design of 1 Pancras Square, London, and the Edinburgh Centre for Carbon Innovation, the University of Edinburgh, respectively. In relation to 1 Pancras Square, London, the project architect elaborated further, emphasizing that a holistic sustainability approach was used throughout the design process. With reference to the Edinburgh Centre for Carbon Innovation, the University of Edinburgh, the respondent highlighted the importance of design harmonizing well with nature, cautioning against processes that flaunt nature risk unnaturalness. Some of the respondents' answers were generally broad, reflecting a more holistic approach stemming from their design philosophy.

The majority of the design firms from the sample confirmed applying an NBD approach in one stage of the RIBA PoW: **Stage 0—**Strategic definition, Stage 1—Preparation and briefing, and Stage 2—Concept design. Among those who applied an NBD approach in Stage 0 (Strategic definition) of the RIBA PoW, nearly all the BREEAM Outstanding-rated projects were fire stations designed by BDP, with the exception of the White Collar Factory, London, by Allford Hall Monaghan Morris.

The portion of design projects that utilized an NBD approach at **Stage 1** included the GlaxoSmithKline Carbon Neutral Laboratories for Sustainable Chemistry, the University of Nottingham, by the Fairhursts Design Group; Project Lima, London, by Magnus & Associates; and the Featherstone Building, London, by Morris + Company. Regarding Project Lima, London, the project architect provided additional insights and stated that the client expressed a keen interest in showcasing sustainability in construction from the inception of the project. The brief required a dedicated sustainability approach in specifying all materials and construction methods by all consultants, including interior design elements. As Magnus & Associates were responsible for the interior design, this required specific research into the suitability of the materials and products, spanning from carpets and paint to wall coverings, furniture, and fabrics. This research commenced during the concept design phase and continued seamlessly through manufacturing and construction. In relation to the Featherstone Building, London, by Morris + Company, the project architect emphasized that the inclusion of planting elements and biophilia was integral to the design for the rooftop terrace spaces from the outset of the design process.

A subset of the design projects, which utilized an NBD approach at **Stage 2,** comprised 11–21 Canal Reach, London, by Bennetts Associates; Aurora Offices, Bristol, by Willmott Dixon; and the Big Data Institute (BDI), Headington, by Make Architects. Regarding 11–21 Canal Reach, London, the project architect mentioned applying a roof garden concept at this stage, focussing on biophilia (i.e., creating green spaces for the occupants). Concerning Aurora Offices, Bristol, the respondent indicated that the aspiration of the client was for the project to be the most sustainable office in Bristol and so nature was always going to be a feature of the design.

Evidence of the application of NBD approaches **at both Stage 1** (Preparation and briefing) **and Stage 2** (Concept design) was only found in one project (Building R7, London) by Duggan Morris Architects. The project architect also mentioned having a rooftop garden as a potential office amenity and wanted an active ground floor, feeling that a well-thought-out planting strategy would be a beneficial addition in both cases.

A subset of the design firms confirmed applying NBD approaches in **five stages** of the RIBA PoW. The related projects included Filwood Green Business Park, Bristol, by Stride Treglown (Stage 1–5); Temple Farm, Chelmsford, by Murdoch Wickham (Stage 0–4); and The Catalyst, Newcastle University, by GSS Architecture (Stage 1–5). In relation to Filwood Green Business Park, Bristol, the project architect emphasized their aim to achieve a high level of biodiversity within the development, incorporating features such as an ecology zone and green roofs (initially exploring both intensive and extensive options). They also mentioned careful specification of a range of native species and considerations of bio-utilization with material selections, such as timber cladding and an initial analysis of using structural insulated panels for wall build ups.

Evidence of the application of NBD approaches in **six stages** (Stage 0–5) of the RIBA PoW was only found in one project (Prince Charles House, Cornwall) by PRP Architects.

Similarly, evidence of the application of NBD approaches in **seven stages** (Stage 1–7) of the RIBA PoW was found in Worcester Library & History Centre, Worcester, by Feilden Clegg Bradley Studios. The project architect specified that the design was based, from initial concept through to completion, on harnessing the natural processes of maximizing (but controlling) daylight and regulating temperature through thermal mass and air movement.

The remaining respondents for the BREEAM Outstanding-rated projects (Elliott's Field Shopping Park Phase II, Rugby, by Piper Whitlock Architecture; John Lewis, York, by Brookerflynn Architects; and the Saw Swee Hock Student Centre, the London School of Economics, by O'Donnell + Tuomey Architects) indicated that they did not utilise an NBD approach in the design of their projects.

3.1.2. Application of NBD Approaches and BREEAM Categories

NBD in the BREEAM categories was most prominent in land use and ecology (11.4%), followed by health and well-being (10.4%); energy (9.8%); materials (9.3%); innovation (8.8%); transport (8.3%); water (8.3%); waste (7.7%); resilience, resources and pollution (each 6.8%); and lastly, management (5.6%) (Figure 3). A portion of the total respondents confirmed that NBD approaches were used for **all BREEAM categories**. This included the design of all fire stations by BDP; the Edinburgh Centre for Carbon Innovation, the University of Edinburgh, by Malcolm Fraser Architects; and Prince Charles House, Cornwall, by PRP Architects. Regarding the Edinburgh Centre for Carbon Innovation, the University of Edinburgh, the project architect expressed that all processes are natural and that they avoid forcing artificial elements onto the design of their buildings. In relation to the Prince Charles House, Cornwall, the respondent confirmed that the Cornish Eco Town project inspired the project, with the Eden Project serving as an inspiration to include growing plants and their benefit to residents. Similarly, for the design of 1 Pancras Square, London, by David Chipperfield Architects, NBD approaches were used for **all BREEAM categories except for the categories of management and resources**.

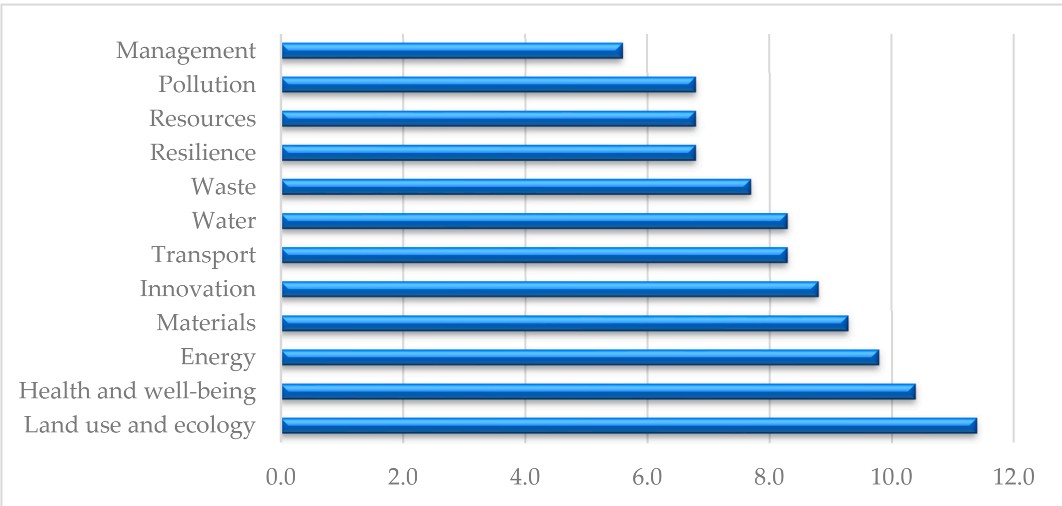

Figure 3. Percentage of application of NBD in the BREEAM categories.

Another example was of GlaxoSmithKline Carbon Neutral Laboratories for Sustainable Chemistry, the University of Nottingham, by Fairhursts Design Group, where the project architect applied NBD approaches for **all BREEAM categories except for the categories of management, resilience, and transport**. A subset of the design firms agreed that they applied NBD approaches for only **one BREEAM** category (land use and ecology). These projects included 11–21 Canal Reach in London, by Bennetts Associates and The Featherstone Building in London by Morris + Company. For the project on 11–21 Canal Reach, London, the project architects from Bennetts Associates highlighted that additional species were considered for roof garden/biodiverse roofs. Regarding the Featherstone

Building, London, the respondent mentioned that they installed planters and natural planting elements at the rooftop level.

Some of the project architects confirmed that they applied an NBD approach for **two BREEAM categories**. These projects comprised Building R7 in London, by Duggan Morris Architects (health and well-being and land use and ecology) and Temple Farm, Chelmsford, by Murdoch Wickham (land use and ecology and innovation). For Building R7 in London, the project architect expressed that they utilized biodiversity through plant species on the roof for land use and ecology, while health and well-being benefits were present due to provision of outdoor spaces on every office floor plate, providing access to fresh air and views to green space and environment—with the best being on the top floor featuring a rooftop garden and view over London.

Evidence of the application of NBD approaches for **three BREEAM categories** (health and well-being, land use and ecology, and materials) was found only in one project (Aurora Offices, Bristol) by Willmott Dixon. The project architect stated that they utilized natural materials and considered biophilic design to improve user experience.

Evidence of the application of NBD approaches for **four BREEAM categories** (energy, health and well-being, materials, and innovation) was found in one project (White Collar Factory, London) by Allford Hall Monaghan Morris.

A subset of the design firms validated that they used NBD approaches for **five BREEAM categories**. This included the Big Data Institute (BDI) in Headington, by Make Architects (energy, innovation, land use and ecology, transport, and waste) and Filwood Green Business Park in Bristol by Stride Treglown (energy, health and well-being, land use and ecology, transport, and water). The project architect of the Big Data Institute (BDI) in Headington expressed that from the outset of Stage 2—Concept Design, a labyrinth was introduced to reduce the requirement of air-conditioning of the building. Air is drawn through three tunnels, which can cool the air by up to 10 degrees (or warm it during the winter) before it is fed through air-conditioning and into the floorplates. This use of the ground thermal mass reduces the amount of energy required to cool or heat the air. An ecologist was involved to assess the natural habitat and provide insight into the new landscaping and the biodiverse roof. A transport study was undertaken to minimize the number of people driving to work by a bicycle parking strategy was introduced for the campus and waste storage facilities was calculated against the BREEAM requirements. The project architect of Filwood Green Business Park, Bristol, reported that for energy, they used the building section, a highly insulated façade, and that the heating/ventilation strategy was chosen with the primary aim of reducing energy consumption. For water, they looked at greywater and reduced water consumption within the building with careful specification of sanitaryware. The project architect further iterated that they introduced extensive cyclist facilities next to the proximity of Metrobus public transport links and audio-visual installations detailing bus arrival/departure times, which were essential for reducing car reliance.

A subset of the project architects validated that they used NBD approaches for **six BREEAM categories**. This included The Catalyst, Newcastle University, by GSS Architecture (energy, health and well-being, land use and ecology, materials, transport, and water); and Worcester Library & History Centre, Worcester, by Feilden Clegg Bradley Studios (energy, health and well-being, innovation, land use and ecology, materials, and resilience). The project architect of Worcester Library & History Centre in Worcester explained that for the BREEAM category of energy, they utilized heating using woodchip boilers, cooling using river water, and an extensive use of daylighting. For health and well-being, they extensively used natural materials and finishes, ensured clear circulation and orientation in the architectural design, and provided good daylighting and visual contact with the outdoors. In relation to land use and ecology, the project architect designed flood control water attenuation basins and planted them with mixed wildflowers. For innovation, they implemented cooling strategies using river water and a labyrinth thermal mass. In one project (Project Lima, London) by Magnus & Associates, NBD approaches were applied across **seven BREEAM categories**: energy, health and well-being, materials, resources, transport, waste, and water. The design team emphasized sustainability in materials and products, using natural, untreated oak wall cladding and water-based lacquer on furniture. They also influenced a furniture supplier's manufacturing process to align with sustainability goals. Additionally, they specified fully recyclable or natural fabrics, carpets with high recycled content, and freestanding planters throughout the floor plate as room dividers or decorative elements on top of storage cabinets to soften the workplace appearance.

Among the remaining respondents for the BREEAM Outstanding-rated projects (Elliott's Field Shopping Park Phase II, Rugby, by Piper Whitlock Architecture; John Lewis, York, by Brookerflynn Architects; and the Saw Swee Hock Student Centre, the London School of Economics, by O'Donnell + Tuomey Architects), NBD approaches were not utilized across any of the BREEAM categories for their projects.

3.1.3. Professions Who Contributed to NBD to Improve Sustainability

Professionals involved in NBD applications were architects, interior designers, indoor plant specialists, chemists, net zero carbon specialists, ecologists, environmental designers, environmental engineers, landscape architects, and sustainability consultants (Figure 4).

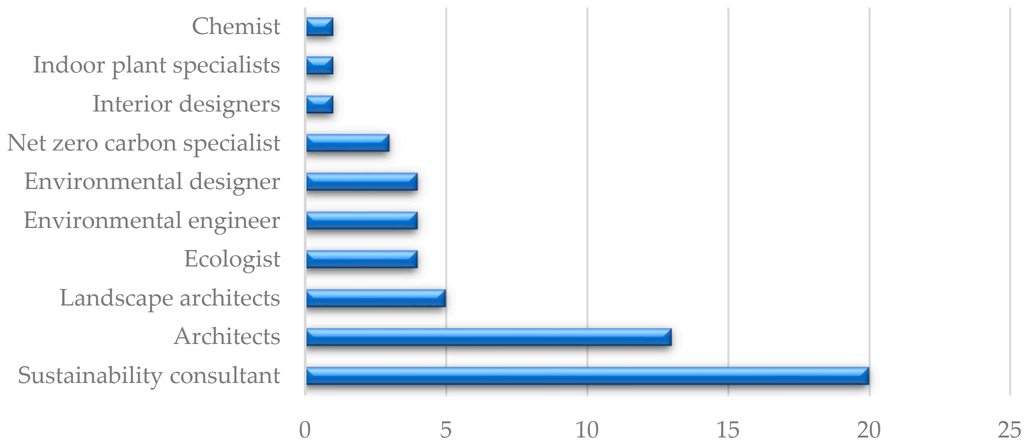

Figure 4. Professions involved in design teams that incorporated NBD in the surveyed BREEAM Outstanding projects.

The design team of the Edinburgh Centre for Carbon Innovation, the University of Edinburgh, by Malcolm Fraser Architects revealed that **architects** were involved in contributing to NBD to improve the project's sustainability. The respondent further elaborated that architects have the professional responsibility that compels them to care for issues around waste, reuse, energy, and culture. The design team members of Murdoch Wickham of Temple Farm, Chelmsford, specified that **landscape architects** were needed for applying NBD to improve sustainability. Some projects relied solely on **sustainability consultants** for incorporating NBD into the design; for example, of 1 Pancras Square, London, by David Chipperfield Architects and Prince Charles House, Cornwall, by PRP Architects.

Many respondents noted the necessity of engaging two professions to integrate NBD approaches for enhancing sustainability. These projects encompassed all fire stations in London by BDP (**architects** and **sustainability consultants**); 11–21 Canal Reach, London, by Bennetts Associates (**ecologist** and **sustainability consultant**); Building R7, London, by Duggan Morris Architects (**landscape architect** with good plant selection skills and **sustainability consultant**); and White Collar Factory, London, by Allford Hall Monaghan Morris (**environmental engineer** and **sustainability consultant**).

Some design teams specified that they required three professions to incorporate NBD approaches for improving the sustainability of their projects. These projects included Aurora Offices, Bristol, by Willmott Dixon (**architects**, **environmental designer**, and **sus-**

tainability consultant); Filwood Green Business Park, Bristol, by Stride Treglown (**ecologist**, **landscape architect**, and **sustainability consultant**); and Project Lima, London, by Magnus & Associates (**indoor plant specialists**, **interior designers**, and **sustainability consultant**). The respondent for Project Lima, London, from Magnus & Associates further explained that they closely collaborated with the indoor plant specialists to incorporate natural elements into design.

Some design teams revealed that they needed four professions to incorporate NBD approaches to improve the sustainability of their projects. These projects included the Big Data Institute (BDI), Headington, by Make Architects (**ecologist**, **environmental designer, environmental engineer**, and **sustainability consultant**); GlaxoSmithKline Carbon Neutral Laboratories for Sustainable Chemistry, the University of Nottingham, by Fairhursts Design Group (**architects**, **chemist**, **landscape architects**, and **net zero carbon specialist**); The Catalyst, Newcastle University, by GSS Architecture (**environmental designer, environmental engineer, net zero carbon consultant, and sustainability consultant**); The Featherstone Building, London, by Morris + Company (**architect, ecologist, landscape architect, and sustainability consultant**); and the Worcester Library & History Centre, Worcester, by Feilden Clegg Bradley Studios (**environmental designer, environmental engineer, net zero carbon specialist, and sustainability consultant**). The project architect for the Big Data Institute (BDI), Headington, from Make Architects confirmed that when the building was conceived conversations were not focused on carbon as they are today. The project architect for GlaxoSmithKline Carbon Neutral Laboratories for Sustainable Chemistry, the University of Nottingham, from Fairhursts Design Group mentioned that a holistic approach was adopted by the client/academics and consultants teams. The project architect who designed The Featherstone Building, London, from Morris + Company commented that the sustainability consultant reviewed the targets for BREEAM, and architects, ecologists, and landscape architects contributed to the design.

Other project architects for the BREEAM Outstanding-rated projects (Elliott's Field Shopping Park Phase II, Rugby, by Piper Whitlock Architecture; John Lewis, York, by Brookerflynn Architects; and the Saw Swee Hock Student Centre, the London School of Economics by O'Donnell + Tuomey Architects) indicated that they did not need the involvement of other professions, as they did not utilize NBD approaches to improve the sustainability of their projects.

Critical findings pertinent to the survey on engagement of architects in NBD using RIBA PoW were as follows: (i) 20% of the project architects who designed a BREEAM Outstanding building in the UK confirmed that they utilised a NBD approach at one or more stages of the RIBA PoW; (ii) the project architects revealed that the extent of the application of NBD approaches decreases from Stage 0 to Stage 7; the application of NBD approaches was most prevalent in their projects at Stage 0 (Strategic Definition); (iii) the application of NBD approaches was most prominent for the BREEAM category of land use and ecology; and (iv) various projects relied on the involvement of different professionals who incorporated NBD approaches to improve the sustainability of related projects. Surprising trends included the declining use of NBD approaches from Stage 0 to Stage 7. The higher focus at Stage 0 (Strategic Definition) might indicate an emphasis on initial vision-setting for sustainability but the subsequent decline suggests potential gaps in carrying these strategies through to Stage 6 (Handover) and Stage 7 (Use).

4. NBD Overlay of RIBA PoW 2020: Guidelines for TDC in the NBD of Buildings

4.1. Adapting the General Transdisciplinary Framework into Guidelines for TDC in the NBD of Buildings

Previous research developed and tested a general framework for conducting TDR [35]. This subsection explains how the terminology of the general transdisciplinary framework [35] (Figure 5) was adapted to the outcomes of all stages of RIBA PoW 2020. Table 1 presents suggested outputs of the general transdisciplinary framework [35], outputs of the RIBA PoW 2020 stages, and adapted terminology for architects. This adaptation and integration were necessary to identify key ideas to develop guidelines for TDC for the NBD of sustainable buildings aligned with the RIBA PoW 2020 and with related actions for Initiation, Management, and Knowledge Exchange.

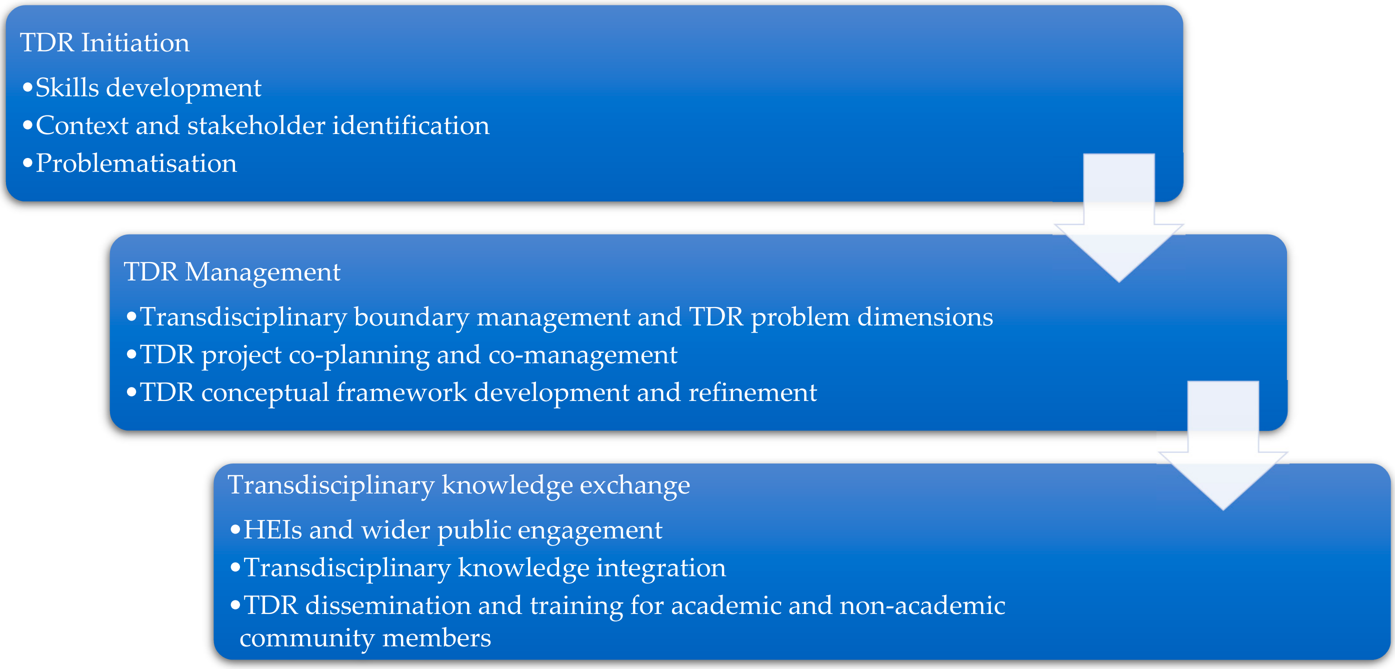

Figure 5. A general framework for conducting transdisciplinary research (TDR) adapted from Butt and Dimitrijević [35].

Table 1. Guidelines and outputs of the general framework for TDR, the RIBA PoW stages and outcomes, and the adapted guidelines for NBD of buildings.

Guidelines and Outputs from the General Framework for TDR	RIBA PoW Stages and Outcomes	Adapted Guidelines for NBD of Buildings
Recommendations on collaborative learning environments, responsible research and innovation, and interdisciplinary working.	Stage 0 Strategic Definition Outcome: Confirmed client requirements	Discuss and agree with the client to complete the following: adopt NBD approaches; define NBD-related objectives; adopt or develop NBD-related innovations; identify NBD-related disciplines that should be included in the team.
Diagrams: Innovation ecosystems and the team of scientist/researchers for the TDR project.	Stage 1 Preparation and Briefing Outcome: Project brief approved by the client and confirmed to be accommodated on the site.	Obtain the client's approval of the project brief and the proposed interdisciplinary team members who will collaborate on the site assessment.
Formulate joint TDR problem.	Stage 2 Concept Design Outcome: Architectural concept approved by the client and aligned to the project brief.	Obtain client's approval of the architectural concept that includes NBD approaches and is aligned with the project brief.
Diagrams: Site related-dimensions of the TDR problem and stakeholder mapping.	Stage 3 Spatial Coordination Outcome: Architectural and engineering information spatially coordinated.	Extract architectural and engineering information related to the proposed NBD solutions and define their spatial relationships. Consult and obtain approval from planners and other relevant agencies for integration of the NBD solutions at the construction site.

Table 1. *Cont.*

Guidelines and Outputs from the General Framework for TDR	RIBA PoW Stages and Outcomes	Adapted Guidelines for NBD of Buildings
An overview of relevant case studies and their results, including related TDC.	Stage 4 Technical Design Outcome: All design information required to manufacture and construct the project completed.	Interdisciplinary coordination (including potential manufacturers and construction team) and design reviews to prepare and validate manufacturing and construction information related to the NBD solutions.
A TDR framework for the project on which the team will collaborate.	Stage 5 Manufacturing and Construction Outcome: Manufacturing, construction, and commissioning completed.	Coordination and collaboration between the construction team and the transdisciplinary design team to complete the construction phase.
A diagram of the TDC, descriptions of the research findings, and draft papers for dissemination and project promotion.	Stage 6 Handover Outcome: Building handed over, aftercare initiated, and building contract concluded.	Comprehensive documentation and training on the operation and maintenance of the NBD solutions for building users.
Training and development plan, summative evaluation criteria, and summative evaluation of the transdisciplinary knowledge exchange processes.	Stage 7 Use Outcome: Building used, operated, and maintained efficiently.	Post-occupancy evaluation of the NBD solutions leading to knowledge exchange sessions between the transdisciplinary team members for future projects.

4.2. TCF for the NBD Overlay of Sustainable Buildings Aligned with the RIBA Plan of Work 2020

The TCF for the NBD Overlay of sustainable buildings entails TDC; holistic approaches; customization for NBD; inclusive stakeholder engagement; a transdisciplinary learning environment; emphasis on responsible research and innovation; and adaptability and scalability. To ensure the proposed actions within the TCF for the NBD of sustainable buildings are relevant, the stages and processes of the RIBA PoW 2020 were analysed to identify overlapping phases and complementary areas, map the NBD Overlay to existing stages, and validate it through stakeholder consultation.

A TCF for the NBD of sustainable buildings (Appendix A, Tables A1–A8) has three phases: Initiation, Management, and Knowledge Exchange, identified through systematic literature reviews [35,36] and later included in the general framework for conducting TDR [35]. The **Initiation phase** entails identifying project stakeholders from the beginning to ensure inclusivity and multiple perspectives when defining the objectives and goals of building projects in which NBD will be implemented and to commence collaborative interdisciplinary working.

The **Management phase** is crucial for coordinating the efforts of the NBD team, client team, and construction team. It requires effective communication channels to facilitate collaboration and coordination and manage project timelines and deliverables. In TDC, it is possible for conflicts to arise due to differences in perspectives and approaches. The Management phase provides opportunities to address conflicts constructively and to encourage a positive and cooperative working environment. The Management phase enables efficient resource allocation, including finances, expertise, and time, to be appropriately assigned to support the collaborative design process.

The **Knowledge Exchange phase** emphasizes learning from different disciplines and stakeholders. It integrates different knowledge domains to reinforce the NBD implementation. By sharing knowledge, expertise, and best practices, teams develop more innovative and effective solutions. Lessons from previous phases of various stages and experiences are shared and applied to enhance the NBD process and project outcomes. Knowledge exchange allows the outcomes and achievements of the framework to be shared beyond the specific project. Disseminating insights and successful practices has the potential to create a legacy that influences future sustainable building projects for a wider culture of NBD adoption.

In conclusion, the Initiation, Management, and Knowledge Exchange phases are fundamental elements of the NBD Overlay. They set the direction for the collaborative design process, ensure effective coordination and resource management, and facilitate knowledge exchange, leading to a more comprehensive and successful NBD implementation.

Appendix A presents the proposed NBD Overlay to the RIBA PoW 2020, comprising TCF for the NBD of sustainable buildings and shows the related tasks for Initiation, Management, and Knowledge Exchange.

4.3. Recommendations for Possible Training of NBD Team

Training of the NBD team implementing the TCF is crucial to understand the framework, collaboration and communication, NBD solutions and best practices, interdisciplinary learning, responsible research and innovation, addressing challenges, stakeholder engagement, monitoring and evaluating, and contribution to knowledge exchange. Table 2 presents the recommendations for possible training of NBD team related to the TCF for NBD of sustainable buildings aligned with the RIBA PoW 2020. The possible format to deliver this training could be an MSc programme that could be developed to train trainers. The graduates of this programme could develop their future careers as NBD Management Coordinator or NBD Knowledge Exchange Coordinator/Manager. Other related careers could include being part of sustainable architecture firms, urban planning and development, environmental and sustainability consulting, research and development, green building certifications, academic and teaching positions (to mentor future architects and sustainability professionals), and entrepreneurship and start-ups offering specialised services related to NBD solutions.

Table 2. Recommendations for possible training of NBD team for applying the TCF for NBD of sustainable buildings.

Stage of RIBA PoW 2020	Possible Training of NBD Team for Applying TCF for NBD of Sustainable Buildings
Stage 0: Strategic Definition	(1) A scoping exercise: Review the project requirements and objectives to determine the scope of the NBD solutions needed; (2) Collaborative planning workshops: To understand the processes of interdisciplinary design and transdisciplinary collaboration projects; (3) NBD goal setting workshop: To familiarise team members how sustainability objectives, including NBD objectives can align with the client requirements using goal setting techniques such as SMART (Specific, Measurable, Achievable, Relevant, Time-bound) framework; (4) Collaborative business case development session: To train team members on the process of developing a business case for NBD solutions.
Stage 1: Preparation and Briefing	(1) Collaborative workshops: To encourage interdisciplinary collaboration and open dialogue to incorporate diverse perspectives related to NBD solutions and ensure a comprehensive brief.
Stage 2: Concept Design	(1) Interdisciplinary concept design workshop: To train and develop brainstorming skills necessary to explore NBD concepts.
Stage 3: Spatial Coordination	(1) Interdisciplinary design solutions workshop: To discover, apply, and present applications of NBD solutions to Architectural Concepts that balance aesthetics, functionality, and sustainability.
Stage 4: Technical Design	(1) NBD case study analysis: Training workshops or presentations that explore successful NBD case studies from different project types and scales. Learning from real-world examples helps participants understand the application and potential of NBD in similar contexts.
Stage 5: Manufacturing and Construction	(1) Interdisciplinary collaboration in construction for NBD solutions workshop: To enable interdisciplinary collaboration among project participants including NBD team members, and construction team members for the implementation of NBD solutions.
Stage 6: Handover	(1) Effective Hand Over communication workshop: To develop effective communication and training materials for providing induction to building owners, facility managers, and maintenance personnel who will be responsible for the ongoing maintenance of the NBD solutions.
Stage 7: Use	(1) Transdisciplinarity for sustainable buildings through NBD solutions workshop: To train the NBD team members by exploring previous projects to identify the bespoke information needed for Initiation, Management, and KE at various stages of the RIBA Plan of Work as seen in case studies, presentations, and publications.

5. Validation of the Proposed NBD Overlay to the RIBA PoW

Validation of the proposed NBD Overlay was undertaken through an online survey of project architects who confirmed that they applied NBD at any stage of the RIBA PoW for designing their BREEAM Outstanding projects and of the wider community of Chartered Members of the RIBA to confirm whether the Initiation, Management, and Knowledge Exchange of each stage was logical. The planned validation encountered limitations regarding the time required from busy architects to respond to the online survey and find a mutually convenient time for communication regarding any queries they might have had.

5.1. Survey Participants

The first group of survey participants were architectural firms who engaged in NBD for BREEAM Outstanding-rated projects [52]. The second group of study participants was identified within the consultation groups engaged in the development of existing overlays to the RIBA PoW. The third group of study participants was identified through the RIBA's and ARB's Registers of Architects. These registers were used to identify UK architectural practices for the survey [50] to be forwarded to their architects. RIBA-registered architects were also contacted through LinkedIn following an initial poll to identify study participants interested in transdisciplinarity, NBD approaches, and sustainable buildings.

5.2. Research Results

The first question aimed to identify the architectural firm in which a RIBA registered architect is employed. Table 3 presents an anonymised list of RIBA registered architects, indicating architectural practices in which they work (n = 16), who validated the proposed NBD Overlay of the RIBA PoW 2020, comprising the TCF for the NBD of sustainable buildings.

Table 3. Anonymised list of RIBA registered architects, indicating architectural practices in which they work, who validated the proposed NBD Overlay to the RIBA PoW 2020.

RIBA Registered Architect	Related Architectural Firm
A1	Farrell & Clark LLP
A2	Magnus & Associates
A3	Stride Treglown
A4	Stride Treglown
A5	Make Architects
A6	Chapman Taylor
A7	PRP
A8	Allford Hall Monaghan Morris (AHMM)
A9	Ecologic Architects
A10	Feilden Clegg Bradley Studios
A11	WilkinsonEyre
A12	RSHP
A13	MH Architects
A14	Zameen Developments
A15	Foster + Partners
A16	Morris + Company

The number of study participants is justified due to a wide range of participants representing diverse perspectives, expertise, and experiences, providing a more comprehensive validation of the framework's effectiveness and relevance. The previous overlays to the RIBA PoW had the following study participants, contributors, or members of their respective consultation groups: the Engagement Overlay (n > 40); the DfMA Overlay (n = 39); the Inclusive Design Overlay (n = 17); the Smart Building Overlay (n = 16); the BIM Overlay (n = 8); the Security Overlay (n = 7); the Passivhaus Overlay (n = 7); and the Green Overlay (n = 7). It is worth mentioning that the consultation group of the DfMA Overlay to the RIBA PoW was large as it focused on architecture, offsite construction, and manufacturing techniques in the design and construction process. Two architectural firms from the consultation group of the DfMA Overlay also responded to the invitation to validate the NBD Overlay.

The survey questions aimed to consult the RIBA-registered architects on whether they agree or disagree with the actions within the proposed NBD Overlay of the RIBA PoW 2020, as related to Initiation, Management, and Knowledge Exchange (Table 4).

Table 4. Survey results on the actions within the proposed NBD Overlay of the RIBA PoW 2020.

RIBA PoW Stage	Positive Response	Negative Response
Stage 0: Strategic Definition	93.8% (15)	6.2% (1)
Stage 1: Preparation and Briefing	81.3% (13)	18.7% (3)
Stage 2: Concept Design	93.8% (15)	6.2% (1)
Stage 3: Spatial Coordination	87.5% (14)	12.5% (2)
Stage 4: Technical Design	93.8% (15)	6.2% (1)
Stage 5: Manufacturing and Construction	93.8% (15)	6.2% (1)
Stage 6: Handover	87.5% (14)	12.5% (2)
Stage 7: Use	93.8% (15)	6.2% (1)

Each survey question invited comments or suggestions. Stages 0, 2, 4, 5, and 7 would have had a 100% positive response if there had not been an outlier (A10) who commented that the NBD Overlay is fine, but that their main concern was related to the financial resources needed to implement it.

One respondent (A1) questioned the suitability of establishing a design team at Stage 0 (Strategic Definition). Another architect (A4) acknowledged the benefits the client can have due to the definition of NBD and its related features at the beginning of Stage 0 and added that the definition can assist clients or stakeholders to understand NBD's scope. They also mentioned that an ecologist's early input in the process would enable developing a baseline analysis to understand the biodiversity net gain (BNG) and define the required level of NBD to assist achieving planned and/or client's targets.

Several comments were related to the proposed NBD Overlay actions at Stage 1 (Preparation and Briefing). Architects A3, A7, and A8 mentioned that liaising with contractors may be too early and may not provide meaningful results as only strategic and tactical discussions take place at that stage. Another architect (A13) mentioned that project requirements may change the work process as local development plans and client's objectives may vary and would require planning from regional and national bodies, depending on the size of the development, which may be difficult to affect change related to national development planning. Lastly, the respondent (A16) stated that they typically would not engage with contractors until much later.

Comments on the actions in the proposed NBD Overlay related to Stage 2 (Concept Design) mentioned that the link to mechanical, electrical, and plumbing (MEP) does not seem to be included (A3), and that the concept design stage should also consider the building site and effect on adjacent sites (A13).

Regarding the application of the proposed NBD Overlay in Stage 3 (Spatial Coordination), an architect (A3) specified that NBD studies should start in Stage 2 (Concept Design). Another architect (A5) stated that Change Control is good but can become bureaucratic and hard to implement if introduced too soon when the design is constantly evolving. Another suggestion was that the direction or approach needs to be considerate of the size of a project to be a viable process that adds value to the work (A13). Finally, an architect (A14) highlighted that they agree with the proposed actions related to Initiation, Management, and Knowledge Exchange of the NBD Overlay and declared that it is important to have additional knowledge sharing discussions directly with the client, especially once a feasibility study is completed and potential options are presented.

Comments related to the application of the proposed NBD Overlay in Stage 4 (Technical Design) included a remark that identification of new NBD measures is unlikely as these will have been set at Stage 3 (Spatial Coordination), while at Stage 4 these will simply be developed in more detail (A4). They further suggested that as it seems that there may be a big crossover with Landscape Architecture and that landscape architects can be included within the core team at this stage.

Regarding the application of the proposed NBD Overlay in Stage 5 (Manufacturing and Construction), an architect (A3) agreed with the presented workshop-based approach. Another architect (A13) specified that at this stage it may be vital to consider certification for sustainability and that related options and measures needed to possibly set up at the outset.

Comments related to the application of the proposed NBD Overlay in Stage 6 (Handover) included a remark that the NBD team may be unlikely to undertake seasonal commissioning and may only monitor changes (A3). Another architect (A4) added that the contractor would likely be leading the handover process rather than the NBD team. Lastly, an architect (A14) agreed with the proposed actions related to the Initiation, Management, and Knowledge Exchange of the NBD Overlay and stated that post-completion and handover need to accompany the preplanning stages to ascertain best practices and report lessons learnt.

While agreeing with the actions of the proposed NBD Overlay related to Initiation, Management, and Knowledge Exchange, an architect (A13) cautioned to take account of the scale of a project as general compliance for larger development projects may need greater sustainability requirements and responses. They mentioned this because they had experience with large projects of over 50 hectares where environmental impact surveys were needed to evidence sustainability credentials for sustainability certifications, to identify design impact, and to review product delivery and best practice solutions for operation and work processes. Similarly, another architect (A16) stated that everything aligns with the RIBA PoW and presented ideas for potential further research as they mentioned that a practical example of how NBD may relate to a project throughout a design stage could be provided as it would be useful to understand the practical application of the proposed NBD Overlay in reality.

The validation of the proposed NBD Overlay of the RIBA PoW 2020 through the above consultation with architects has yielded highly positive results (Table 4), indicating that they recognize the importance of incorporating NBD principles and TDC in SBD. They acknowledged the TCF's potential to guide and enhance the implementation of nature-based strategies and solutions, responsible research and innovation, and stakeholder engagement throughout the architectural project lifecycle. Continuous improvement and refinement based on the respondents' and potential future feedback and application will be essential to ensure the guidelines for the NBD of buildings to remain adaptable and responsive to the dynamic challenges of sustainable architecture. In conclusion, a framework that fosters TDC and promotes NBD approaches, principles, and solutions has the potential to facilitate design of sustainable architecture, driving the industry towards a more resilient and environmentally conscious built environment.

6. Results

The survey investigating the engagement of architects with nature-based design (NBD) within the framework of the RIBA Plan of Work (PoW) provided several significant insights. It was identified that 20% of project architects responsible for designing BREEAM Outstanding buildings in the UK implemented NBD approaches during one or more stages of the RIBA PoW. The findings further indicated that the extent of NBD application diminished progressively from Stage 0 (Strategic Definition) to Stage 7, with Stage 0 emerging as the stage where NBD methodologies were most extensively utilized. Notably, the application of NBD was most pronounced in addressing the BREEAM category of land use and ecology. Additionally, the survey showed the critical role of multidisciplinary collaboration, as various professionals were instrumental in applying NBD strategies to enhance the sustainability outcomes of these projects.

The development and testing of the proposed NBD Overlay relied on the following parts: (i) a survey on the engagement of architects in NBD using RIBA PoW (Section 3); (ii) the adaptation and integration of the general framework for conducting TDR into the RIBA PoW (Section 4); and (iii) a survey to validate that the TCF for the NBD of sustainable buildings aligned with the RIBA PoW (Section 5). Each part presented key findings that enabled the development and validation of the proposed NBD Overlay to the RIBA PoW.

Significant actions related to the adaptation and integration of the general framework for conducting TDR with the RIBA PoW were as follows: (i) *Stage 0 (Strategic Definition)*—discussing and agreeing with clients to adopt NBD approaches, defining NBD-related objectives, adopting or developing NBD-related innovations, and identifying NBD-related disciplines for professionals to be included in the team; (ii) *Stage 1 (Preparation and Briefing)*—obtaining the client's approval of the proposed interdisciplinary team members who will collaborate for the on site assessment; (iii) *Stage 2 (Concept Design)*—obtaining the client's approval of the architectural concept that includes NBD approaches aligned with the project brief; (iv) *Stage 3 (Spatial Coordination)*—extracting architectural and engineering information related to the proposed NBD solutions and defining their spatial relationships and consulting and obtaining approval from planners and other relevant agencies for appropriate integration of NBD solutions at the construction site; (v) *Stage 4 (Technical Design)*—IDC (including potential manufacturers and construction team) and interdisciplinary design reviews for preparing and validating manufacturing and construction information related to the NBD solutions; (vi) *Stage 5 (Manufacturing and Construction)*—coordination and collaboration between the construction team and the transdisciplinary design team to complete the construction phase; (vii) *Stage 6 (Handover)*—comprehensive documentation and training on the operation and maintenance of NBD solutions for building users; and (viii) *Stage 7 (Use)*—the post-occupancy evaluation of NBD solutions leading to knowledge exchange sessions between the transdisciplinary team members for future projects.

Crucial findings corresponding to the survey to validate the proposed NBD Overlay of RIBA PoW 2020, comprising TCF for the NBD of sustainable buildings were as follows: (i) over 80% of the architects responded positively to the TCF actions related to Initiation, Management, and Knowledge Exchange; (ii) the highest number of positive responses were for Stages 0, 2, 4, 5, and 7—93.8% (15); (iii) the high agreement rate signified that RIBA registered architects from notable UK architecture firms recognize the importance of TDC for applying NBD solutions in building design; (iv) strong support from study participants who validated the TCF also ensures that the proposed NBD Overlay holds promise as a valuable resource for architects seeking to create sustainable buildings that harmonize with nature and positively impact communities and the natural environment; and (v) the feedback and insights provided by the architects will further enrich the framework to pave the way for its successful practical implementation in diverse architectural projects. It is also interesting to note that two architectural firms were part of both consultation groups for the DfMA Overlay and the NBD Overlay, which included Stride Treglown and AHMM.

7. Discussion

The research findings provide important insights that align with, expand, and challenge the existing academic literature on nature-based design approaches, sustainable buildings, and interdisciplinary/transdisciplinary collaboration. The research results are contextualised with academic perspectives to highlight their relevance and implications for practice.

The initial survey results on the engagement of architects in NBD at different stages of the RIBA PoW indicated that NBD approaches are most extensively applied during Stage 0 (Strategic Definition) and progressively diminish through later stages of the RIBA PoW. This observation aligns with the literature, emphasizing the importance of early-stage integration of sustainability goals to maximize project impact [56]. Early adoption aligns with frameworks like the Integrated Design Process (IDP), which emphasizes early client engagement and team formation as critical to embedding sustainability principles [57].

However, the survey also reveals limited engagement with NBD in later stages, such as Stages 6 (Handover) and 7 (Use). These findings diverge from calls by authors like Salem, et al. [58] for more robust operational and post-construction strategies to ensure the longevity and efficacy of sustainable solutions.

The research finding that NBD particularly impacts addressing the BREEAM category of land use and ecology shows the potential of NBD in meeting certification goals. Research by Pearlmutter, et al. [59] commented that addressing ecological categories often requires targeted design strategies involving natural systems, such as rainwater harvesting or biodiversity enhancement measures. The alignment of the findings with such studies confirms NBD's role in promoting sustainability metrics. The application of NBD across other BREEAM categories, such as water or energy remains less explored.

Previous research has shown that the planning and design of future BREEAM Outstanding-rated projects for an equitable urban future [60] may need TDC [61–64] through interdisciplinary teams [35,65–67]. This research provides a structured approach due to the proposal of an NBD Overlay to the RIBA Plan of Work 2020, which may impact future BREEAM Outstanding-rated projects as various Project Architects have evidenced NBD applications [52] and validated the proposed overlay (Table 3).

Over 80% of the architects surveyed responded positively to the TCF actions related to Initiation, Management, and Knowledge Exchange of the NBD Overlay, with the highest levels of agreement for Stages 0, 2, 4, 5, and 7. This high level of acceptance signals a growing recognition of transdisciplinary collaboration (TDC) as necessary for achieving sustainability outcomes. Comparable studies [68,69] show the need for structured frameworks to manage and facilitate TDC in architectural projects. The alignment between the survey results and the existing literature strengthens the case for adopting formalized overlays like the NBD Overlay to embed sustainability in practice.

The survey's feedback indicates strong potential for the NBD Overlay as a valuable resource for architects, particularly due to its adaptability to various architectural projects. This aligns with a broad range of the literature [70–72] on the need for customizable sustainability frameworks that cater to diverse contexts. Additionally, the high levels of positive responses validate the practicality of the overlay.

The research conducted to develop and evaluate the NBD Overlay had various limitations that affect the interpretation and applicability of its findings. Firstly, the study is constrained by the availability of data and resources. While attempts were made to include diverse perspectives when surveying the engagement of architects in NBD applications at different stages of the RIBA PoW in BREEAM Outstanding projects, the relatively limited sample size (n = 27 from a population of 120) may not fully capture the breadth of challenges faced in implementing NBD applications. Additionally, the research relies on subjective feedback from professionals and stakeholders, which may introduce potential biases and response variability. Another limitation is the contextual variability inherent in sustainable design projects. The findings are influenced by specific regional, economic, and environmental conditions, which may not be generalizable to all contexts. Similarly, the research primarily emphasizes projects aiming for BREEAM Outstanding certification, potentially narrowing the relevance of insights for other sustainability frameworks or certifications. Finally, the absence of long-term evaluation and metrics within the research limits the ability to assess the durability and scalability of the proposed framework over time.

While the NBD Overlay offers various advantages, its practical application may encounter several challenges. The framework is complex and resource-intensive, requiring significant time, effort, and coordination among interdisciplinary teams. Effective implementation depends on achieving alignment across disciplines with different professional cultures, terminologies, and priorities, which can create barriers to collaboration. Limited awareness and adoption of NBD principles in the AEC industry may slow the framework's integration, particularly in contexts where traditional approaches dominate. Engaging clients throughout the lifecycle of a project may also be difficult, especially if they lack an understanding of the framework's benefits or if their priorities shift. Time constraints, particularly in fast-paced projects, may impede the ability to implement all elements of the NBD Overlay fully. Lastly, assessing the framework's effectiveness requires the development of evaluation frameworks, metrics and long-term monitoring, which can be challenging and may not be feasible in every project.

While acknowledging these potential limitations to the application of the proposed framework in practice, addressing them through continuous improvement, capacity-building, and stakeholder engagement can enhance the TCF's effectiveness and contribute to its successful implementation in sustainable architectural projects. It is essential to recognize that no framework is without limitations, and navigating these challenges can lead to valuable insights and advancements in the field of sustainable architecture.

8. Conclusions

The article aimed to present the development and validation of the proposed NBD Overlay RIBA Plan of Work (PoW) 2020, comprising a TCF for the design of sustainable buildings. The proposed NBD Overlay is flexible and enables the project team to select actions based on their specific project requirements as each project is unique and may have distinct needs, constraints, and objectives. The survey results on the proposed NBD Overlay of RIBA PoW indicate some perceived difficulties (financing, resources) and different views of whether some proposed actions are applied in practice in the proposed stages (e.g., engagement with contractors, etc.). Further research can focus on how the financing problems can be addressed and how a consensus on the proposed actions within stages of the RIBA PoW 2020 may be achieved through a wider consultation.

Potential further research about the TCF for the NBD of sustainable buildings could also explore the prominent ideas pertinent to long-term impact assessment; comparative case studies; economic and social analysis; adaptability and scalability; technology integration; policy and governance; user-centred design; ecosystem services assessment; behaviour change and education; and collaborative tools and platforms. Conducting longitudinal studies to assess the long-term impact of NBD and undertaking comparative case studies between projects that utilised the TCF can help quantify the value of the TCF. Investigating the socio-economic benefits of integrating NBD approaches due to the TCF by assessing factors such as return on investment, health and well-being impacts on occupants, and community resilience can enhance the framework's value proposition. The TCF's adaptability and scalability can be explored across diverse building typologies, project scales, and geographical regions to understand how it can be customized to suit different contexts to broaden its applicability. Advanced technologies, such as Building Information Modelling (BIM), Artificial Intelligence (AI), and Internet of Things (IoT), can support TDC and enhance NBD implementation. Analysing policies, regulations, and governance structures in promoting TDC and NBD adoption by identifying policy incentives or barriers can inform strategies to apply the TCF into broader sustainability agendas. Exploring how user-centred design approaches can be integrated into the TCF can help ensure that the needs and preferences of building occupants are effectively addressed during the design process. Conducting in-depth assessments of the ecosystem services provided by NBD approaches and solutions by quantifying the value of ecosystem services, such as improved air quality, stormwater management, and biodiversity conservation, can strengthen NBD implementation. Investigating how behaviour change interventions and educational programs can promote a deeper understanding of NBD and foster a culture of sustainability among project stakeholders and the wider architectural community would also provide insight in the field. Developing and testing collaborative tools and digital platforms that facilitate enhanced communication among interdisciplinary and transdisciplinary teams (TDTs) working on NBD projects could assist in knowledge exchange for future projects. These research ideas may contribute to a comprehensive understanding of the TCF's potential for contributing to the field of sustainable architecture and enhance its implementation. By addressing these areas, researchers can continue to push the boundaries of improving sustainability in the built environment and promote the widespread adoption of NBD approaches and related NBD solutions.

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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 October 2023). The date of approval is available on request.

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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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Appendix A

NBD Overlay to the RIBA PoW 2020 showing TCF for the NBD of sustainable buildings aligned with the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

Table A1. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 0 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable BuildSSSings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
0	1. Prepare Client Requirements.	1. Confirmed client requirements.	i. Appointing NBD team leaders: The Project Architect (PA) and NBD Management Coordinator (MC).	i. PA and NBD MC identify disciplines that need to be involved in the development of NBD solutions as well as internal experts and potential external consultants in each discipline.	i. Sessions/meetings with internal and external experts in disciplines involved in the development of NBD solutions to identify potential future members of the NBD team.
			ii. Establishing the interdisciplinary NBD team, led by the Project Architect and coordinated by NBD MC, by appointing experts in different disciplines who will be involved in the development of NBD solutions.	ii. The NBD team meets to plan and agree methods for collaborating in the development of NBD solutions.	ii. KE session of NBD team members to share the knowledge and experience of different methods for interdisciplinary and transdisciplinary collaboration (IDC/TDC).
			1. Defining sustainability objectives, including NBD objectives, aligned with the Client Requirements.	1. NBD team meeting to articulate NBD objectives aligned with the Client Requirements.	1. KE session with the client to share the knowledge on possible NBD solutions that can meet the client requirements. Summary report for reference and future KE.
	2. Develop Business Case for feasible options, including review of Project Risks and Project Budget.		2. Collecting data on the feasibility of NBD solutions including potential risks and estimated costs.	2. NBD team members to collaborate in developing the business case for feasible NBD options, including review of related Project Risks and Project Budget based on collected data.	2. NBD team KE session to share the and experience on the feasibility of different NBD solutions, related risks, and costs. Summary report for reference and future KE.

Table A1. *Cont.*

RIBA PoW 2020			TCF for NBD of Sustainable BuildSSSings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
	3. Ratify option that best delivers Client Requirements.		3. Identifying potential NBD solutions that might meet the Client Requirements. Investigating if and how existing NBD solutions might be applied and possibly improved. Reviewing innovative, advanced approaches and recent NBD research outcomes.	3. NBD team to undertake research and report on existing NBD solutions; select those that best meet the Client Requirements considering the feasibility, related risks, and cost; inform the client on innovative, advanced approaches and recent NBD research outcomes to raise awareness of NBD innovations that might be applied in the current or future projects.	3. NBD team share summary reports on existing and emerging NBD solutions and participate in a session to evaluate them and select those that best meet the Client Requirements considering the feasibility, related risks, and cost.
	4. Review Feedback from previous projects.		4. Collecting reports on Post Occupancy Evaluation (POE) on previously applied NBD solutions. *It is recommended to undertake this action in conjunction with the above action no. 3.*	4. NBD team members to provide summary reports on POE of previously applied NBD solutions. *It is recommended to undertake this action in conjunction with the above action no. 3.*	4. NBD team members share summary reports on POE of previously applied NBD solutions for reference and future KE. *It is recommended to undertake this action in conjunction with the above action no. 3*.
	5. Undertake Site Appraisals.		5. Participating in Site Appraisal to understand opportunities and limitations for application of NBD solutions and to include observations in Site Appraisal.	5. NBD team members to provide summary reports on opportunities and limitations for application of NBD solutions based on their disciplinary expertise, experience, and the knowledge of possible regulatory restrictions.	5. NBD team members share summary reports on opportunities and limitations for application of NBD solutions based on their disciplinary expertise, experience, and the knowledge of possible regulatory restrictions, for reference and future KE.

Table A2. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 1 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
1	1. Prepare Project Brief including Project Outcomes and Sustainability Outcomes, Quality Aspirations and Spatial Requirements.	1. Project Brief approved by the client and confirmed that it can be accommodated on the site.	1. Participating in the preparation of the Project Brief by defining how the outcomes of NBD solutions contribute to achieving Sustainability Outcomes, Quality Aspirations, and Spatial Requirements.	1. NBD team members to define how the outcomes of NBD solutions contribute to achieving Sustainability Outcomes, Quality Aspirations, and Spatial Requirements.	1. NBD team KE session to define NBD outcomes and prepare a summary report for the Project Brief.
	2. Undertake Feasibility Studies.		2. Collecting data required to ascertain the feasibility of the selected NBD solutions.	2. NBD team to prepare reports on the feasibility of selected NBD solutions.	2. NBD team knowledge sharing sessions on the feasibility of NBD solutions for reference and future KE.
	3. Agree Project Budget.		3. Collecting data on the cost of manufacturing and developing related to NBD solutions.	3. NBD team liaising with manufacturers and contractors who might work on NBD solutions.	3. NBD Team shares the cost estimates of NBD solutions for reference and knowledge exchange.
	4. Source Site Information including Site Surveys.		4. Acquiring the sourced Site Information to use when developing NBD solutions.	4. Facilitate acquiring the sourced Site Information for the NBD team.	4. NBD team session to discuss implications of Site Information for the development of NBD solutions. Summary report for reference and future KE.
	5. Prepare Project Programme.		5. Collecting data related to NBD solutions required for the preparation of Project Programme.	5. Facilitate NBD team collaboration in collecting data required for the preparation of Project Programme in sections related to the application of NBD solutions.	5. NBD session to review data related to NBD solutions collected for the preparation of Project Programme. Summary report for reference and future KE.
	6. Prepare Project Execution Plan.		6. Collecting data required for defining the execution phase of NBD solutions required for the preparation of Project Execution Plan.	6. Facilitate NBD team liaising with contractors and collaboration in collecting data to define the execution phases of the NBD solutions.	6. NBD team KE session on the execution phases of the NBD solutions in the Project Execution Plan. Summary report for reference and future KE.

Table A3. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 2 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
2	1. Prepare Architectural Concept incorporating Strategic Engineering requirements and aligned to Cost Plan, Project Strategies and Outline Specification.	1. Architectural Concept approved by the client and aligned to the Project Brief.	1. Preparing design concepts of NBD solutions to integrate with Architectural Concept and collecting data required for incorporating Strategic Engineering requirements and aligned to Cost Plan, Project Strategies and Outline Specification.	1. Facilitate collaboration of NBD team in developing design concepts of NBD solutions for integration with Architectural Concept, and in collecting data related to Strategic Engineering requirements and alignment to Cost Plan, Project Strategies and Outline Specification.	1. NBD team KE session on design concepts of NBD solutions prepared for Architectural Concept, including data required for definition of Strategic Engineering requirements for NBD solutions that are aligned to Cost Plan, Project Strategies and Outline Specification for NBD solutions. Summary report for reference and future KE.
	2. Agree Project Brief Derogations.		2. Preparing data for the discussion on Project Brief Derogations that might be related to NBD solutions.	2. Facilitate internal discussions of NBD team regarding Project Brief Derogations related to NBD solutions.	2. NBD team session on Project Brief Derogations that might impact the application of NBD solutions. Summary report for reference and future KE.
	3. Undertake Design Reviews with client and Project Stakeholders.		3. Preparing presentations on design of NBD solutions for Design Reviews with client and Project Stakeholders.	3. Facilitate preparations on design on NBD solutions for the Design Reviews with client and Project Stakeholders.	3. NBD team session to discuss implications of the outcomes of Design Reviews with client and Project Stakeholders on design of NBD solutions. Summary report for reference and future KE.
	4. Prepare stage Design Programme.		4. Preparing descriptions of the design tasks sequences of each member of the NBD team from the start contributing to the completion of the NBD solutions for stage Design Programme.	4. Facilitate collaboration of NBD team in preparing descriptions of the design tasks sequences from the start to the completion of the NBD solutions.	4. NBD team session to elaborate and discuss descriptions of the design tasks sequences from the start to the completion of the NBD solutions.

Table A4. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 3 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
3	1. Undertake Design Studies, Engineering Analysis and Cost Exercises to test Architectural Concept resulting in Spatially Coordinated design aligned to updated Cost Plan, Project Strategies and Outline Specification.	1. Architectural and engineering information Spatially Coordinated.	1. Undertake NBD studies through an integrated design process aided by interdisciplinary collaboration, prepare engineering analysis and cost exercises related to NBD solutions to test Architectural Concept resulting in Spatially Coordinated design aligned to update Cost Plan, Project Strategies and Outline Specification.	1. Facilitate coordination of NBD team for integrating design process aided by interdisciplinary collaboration and preparing engineering analysis and cost exercises related to NBD solutions to test Architectural Concept resulting in Spatially Coordinated design aligned to updated Cost Plan, Project Strategies and Outline Specification.	1. Establish regular interdisciplinary coordination meetings of the NBD team to present NBD studies testing the Architectural Concept. Summary report for reference and future KE.
	2. Initiate Change Control Procedures.		2. Encourage all project stakeholders, including the NBD team and project participants, to identify change requests that relate specifically to NBD initiatives. These requests may involve modifications to the project's design, materials, systems, or processes in order to enhance its performance and align with NBD objectives.	2. Facilitate a systematic process for documenting and tracking change requests related to NBD. This includes recording the details of each change request, such as its nature, rationale, potential impact, and priority. Assign unique identifiers to facilitate tracking and reference throughout the change control process.	2. Conduct an impact assessment session of each NBD-related change requests. This assessment should evaluate factors such as feasibility, cost implications, schedule impacts, and alignment with project objectives and sustainability objectives. Engage relevant experts, such as architects, engineers, and environmental consultants, to provide insights and recommendations regarding the potential impacts of the proposed NBD changes.
	3. Prepare stage Design Programme.		3. Preparing descriptions of the design tasks sequences of each member of the NBD team from the start contributing to the completion of the NBD solutions for stage Design Programme.	3. Facilitate collaboration of NBD team in preparing descriptions of the design tasks sequences from the start to the completion of the NBD solutions.	3. NBD team session to elaborate and discuss descriptions of the design tasks sequences from the start to the completion of the NBD solutions.

Table A5. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 4 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
4	1. Develop architectural and engineering technical design.	1. All design information required to manufacture and construct the project completed.	1. Identify, develop, and accommodate NBD solutions to architectural and engineering technical design.	1. Facilitate collaboration of NBD team to identify, develop, and accommodate NBD solutions to architectural and engineering technical design.	1. Interdisciplinary design review session to validate NBD solutions ensuring compliance with sustainability goals and industry standards.
	2. Prepare and coordinate design team Building Systems information.		2. Prepare and coordinate interdisciplinary NBD team led by the PA and NBD MC to develop Building Systems information.	2. Facilitate collaboration and coordination of NBD team in developing Building Systems information for implementing NBD solutions.	2. NBD KE session to review and validate Building Systems information to implement NBD solutions. Summary report for reference and future KE.
	3. Prepare and integrate specialist subcontractor Building Systems information.		3. Prepare, integrate, and liaise the NBD team with specialist subcontractor to develop Building Systems information for implementing NBD solutions.	3. NBD team liaising with specialist subcontractors who produce Building Systems information to implement NBD solutions.	3. NBD team session to discuss implications of liaising with different specialist subcontractors and their impact on the implementation of NBD solutions.
	4. Prepare stage Design Programme.		4. Preparing descriptions of the design tasks sequences of each member of the NBD team from the start contributing to the completion of the NBD solutions for stage Design Programme.	4. Facilitate collaboration of NBD team in preparing descriptions of the design tasks sequences from the start to the completion of the NBD solutions.	4. NBD team session to elaborate and discuss descriptions of the design tasks sequences from the start to the completion of the NBD solutions.

Table A6. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 5 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
5	1. Finalise Site Logistics.	1. Manufacturing, construction and Commissioning completed.	1. The NBD team participates in on-site activities to finalise the site logistics to collaborate closely with contractors and suppliers for the implementation of NBD solutions.	1. NBD team members consult summary reports from previous projects to consider possible on-site restrictions in relation to the implementation of NBD solutions.	1. NBD team and construction team session to ensure finalisation of the site logistics for the implementation of NBD solutions during construction. Summary report for reference and future KE.
	2. Manufacture Building Systems and construct building.		2. Prepare the interdisciplinary NBD team to collaborate on-site with contractors and subcontractors.	2. Facilitate on-site collaboration between the NBD team and construction teams to realize NBD solutions as part of manufacturing building systems and constructing the building.	2. Maintain open communication channels with contractors, suppliers, and manufacturers involved in the fabrication and installation of NBD solutions.
	3. Monitor progress against Construction Programme.		3. Interdisciplinary NBD team and construction team monitor progress against the Construction Programme and develop NBD milestones that are integrated into the overall Construction Programme that serve as checkpoints for monitoring progress.	3. Facilitate on-site collaboration to align NBD milestone coordination with the Construction Programme and overall construction timeline.	3. NBD KE session to report progress of the Construction Programme and NBD milestones and the completion of construction activities, including NBD solutions.
	4. Inspect Construction Quality.		4. NBD team prepare to inspect the quality of workmanship of NBD solutions and construction quality defined in the final specifications that the construction must comply with.	4. Facilitate the development of an NBD Construction Quality Control Plan to outline the processes and procedures for inspecting construction quality of NBD solutions. The plan includes specific checkpoints, inspections, and tests that are carried out.	4. Monthly report on Construction Quality to be produced for the client team, detailing the quality of the ongoing manufacturing and construction on the project and related NBD solutions. These reports capture the findings, including any deviations from the established quality standards, and provide a record of the construction quality for future KE.

Table A6. *Cont.*

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
	5. Resolve Site Queries as required		5. Contractor prepares questions directed to the NBD team to clarify information in the Building Contract documentation.	5. Facilitate communication between construction team and NBD team to resolve Site Queries as required.	5. NBD team session to include current Site Queries to an NBD Queries Database and prepare a summary report for reference and future KE.
	6. Undertake Commissioning of building.		6. Construction team prepare to undertake Commissioning of building including the calibration and adjustment of building systems manufactured/constructed to realize NBD solutions.	6. Facilitate collaboration of construction team and NBD team during Commissioning of building to support NBD solutions.	6. NBD team session to identify, discuss, and elaborate optimum calibrations and adjustments of building systems related to NBD solutions. Summary report for reference and future KE.
	7. Prepare Building Manual.		7. NBD team liaise with the contractor to prepare Building Manual, which includes all key information including the Health and Safety File, Fire Safety Information, and information related to NBD solutions.	7. Facilitate communication between NBD team and construction team for providing them with detailed instructions regarding the maintenance of Building Systems related to NBD solutions.	7. Workshop of NBD Building Manual with participants including the PA, NBD MC, interdisciplinary NBD team, and construction team to discuss on how the NBD information can be effectively accessed and stored as part of the Building Manual. Summary report for reference and future KE.

Table A7. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 6 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
6	1. Hand over building in line with Plan for Use Strategy.	1. Building handed over, Aftercare initiated and Building Contract concluded.	1. NBD team hand over building in line with Plan for Use Strategy. The hand over will include completing an effective transfer to Facilities Management, including user training, a user friendly Building Manual and any outstanding Asset Information related to NBD solutions.	1. Facilitate NBD team collaboration to complete an effective transfer to Facilities Management, including user training, a user friendly Building Manual and any outstanding Asset Information related to NBD solutions.	1. NBD solutions user workshop: To transfer the necessary knowledge and skills to the building owner or operator regarding the care and maintenance of NBD solutions.
	2. Undertake review of Project Performance.		2. Prepare the interdisciplinary NBD team to evaluate project performance in relation to NBD solutions to determine if they have enhanced biodiversity, improved sustainability, and provided ecosystem services and delivered the intended environmental, social, and economic benefits.	2. Facilitate preparations to evaluate project performance in relation to NBD solutions to determine if they have enhanced biodiversity, improved sustainability, and provided ecosystem services and delivered the intended environmental, social, and economic benefits.	2. A project performance session held by the NBD team to gather their views on the handover and integrating Facilities Management thinking from the start for the benefit of future projects. Summary report for reference and future KE.
	3. Undertake seasonal Commissioning.		3. Prepare the interdisciplinary NBD team to fine tune operational systems during Seasonal Commissioning, with reference to sustainability objectives, including NBD objectives.	3. Facilitate NBD collaboration to fine tune operational systems during Seasonal Comissioning, with reference to sustainability objectives, including NBD objectives.	3. NBD KE session to report effectiveness of the chosen NBD solutions, identify what has worked well, and learn from any obstacles or limitations faced.
	4. Rectify defects.		4. Prepare the construction team and NBD team to rectify any residual defects related to fire safety, health and safety, inclusive design, and NBD solutions as promptly as possible.	4. Facilitate the construction and NBD team to rectify any residual defects related to fire safety, health and safety, inclusive design, and NBD solutions as promptly as possible.	4. NBD team session to discuss most recent rectifications of current project and rectifications from previous projects to identify and report trends. Summary report for reference and future KE.
	5. Complete initial Aftercare tasks including light touch Post Occupancy Evaluation.		5. Prepare the interdisciplinary NBD team to gather feedback on how the building is performing, whether the building and its systems for implementing NBD solutions are being used as planned before the Building Contract is concluded.	5. Facilitate NBD team collaboration to gather feedback on how the building performing, whether the building and its systems for implementing NBD solutions are being used as planned.	5. NBD KE session to report gathered feedback after completing initial Aftercare tasks including light touch POE.

Table A8. NBD Overlay to the RIBA PoW 2020 showing TCF for NBD of sustainable buildings aligned with Stage 7 of the RIBA PoW 2020, including the tasks related to Initiation, Management, and Knowledge Exchange.

RIBA PoW 2020			TCF for NBD of Sustainable Buildings		
Stage	**Core Tasks**	**Stage Outcomes**	**Initiation**	**Management**	**Knowledge Exchange (KE)**
7	1. Implement Facilities Management and Asset Management.	1. Building used, operated and maintained efficiently.	1. Prepare the interdisciplinary NBD team to assist the client team in the implementation of Facilities Management and Asset Management.	1. Facilitate the NBD team to assist the client team in the implementation of Facilities Management and Asset Management.	1. NBD team KE session to share knowledge and experience on assisting the implementation of Facilities Management and Asset Management of different NBD solutions from the current project. Summary report for reference and future KE.
	2. Undertake Post Occupancy Evaluation of building performance in use.		2. Prepare the interdisciplinary NBD team to undertake POE of building performance in use to determine whether the Project Outcomes, sustainability outcomes, NBD outcomes, set out in the Project Brief, or later design targets for Building Systems, have been achieved.	2. Facilitate NBD team collaboration to undertake POE of building performance in use to determine whether the Project Outcomes, sustainability outcomes, and NBD outcomes, set out in the Project Brief, or later design targets for Building Systems, have been achieved.	2. NBD team session to report the current challenges and future opportunities identified from the POE of the implemented NBD solutions. Summary report for reference and future KE.
	3. Verify Project Outcomes including Sustainability Outcomes.		3. Prepare the interdisciplinary NBD team led by PA and NBD MC to verify Project Outcomes, including Sustainability Outcomes, and NBD outcomes.	3. Facilitate interdisciplinary and transdisciplinary collaboration to verify Project Outcomes, including Sustainability Outcomes, and NBD outcomes.	3. PA and NBD MC hold a transdisciplinary KE session to consult NBD team, construction team, client team and review summary reports from Stage 0–Stage 7 to highlight key aspects that would be part of NBD project dissemination, e.g., reports, case studies, presentations, publications.

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