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A Transformed Approach for Benchmarking the Performance of 'Sustainable' Infrastructure

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Abstract: Environmental sustainability priorities for infrastructure development have traditionally focused on aspects including minimising negative impacts in areas such as water and air quality, erosion control, biodiversity and waste management, both in compliance and voluntary frameworks. Associated project performance priorities have focused on avoiding damage beyond 'pre-project baselines'. In contrast, 'best practice' regenerative performance requires infrastructure project outcomes that not only avoid damage but contribute positively to social and ecological systems. For such best practice to become mainstream, industry frameworks, standards and rating schemes must evolve. However, there is limited knowledge regarding 'how' regenerative performance could be encouraged as a business-as-usual infrastructure expectation. This paper therefore explores the potential for a benchmarking methodology called Ecological Performance Standards (EPS) as a transformed approach to facilitate the mainstreaming of regenerative performance expectations. Three research workshops (Phoenix, AZ, USA; Sydney and Brisbane, Australia) were undertaken to investigate the potential for this methodology in infrastructure applications. Mapping was undertaken to align the EPS process steps with associated infrastructure lifecycle phases. Research findings include the synthesis of key opportunities for capturing EPS within infrastructure sustainability rating schemes to leverage current efforts and pivot towards regenerative performance. The authors present a comprehensive matrix mapping 18 ecosystem services against the Infrastructure Sustainability (IS) Rating Scheme credits and categories, summarising where ecosystem services are addressed within the current scheme. The authors conclude the presence of significant opportunities for a new 'business-as-usual' for infrastructure through the integration of regenerative performance benchmarking.

Keywords: benchmarking; sustainability; regenerative; ecosystem services; infrastructure; biomimicry

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1. Introduction

Global trends towards sustainable development are evident in shifting performance expectations from 'business as usual' to incorporating targeted sustainable practices throughout the lifecycle of infrastructure assets and networks. While there has been an emerging international focus on sustainability in recent years, there is a critical need for methods and techniques that would facilitate sustainable appraisal and decision-making at the various project phases [1,2]. Such interfaces span from conceptualisation to design, construction, operation and decommissioning. A range of infrastructure sustainability frameworks are gaining momentum internationally [3–5], and show early progress towards addressing global environmental and social impacts of infrastructure construction and operation. There are existing infrastructure sustainability rating schemes such as CEEQUAL, Envision, IS Rating Scheme and the Living Community Challenge [4,5] that vary in structure and scoping. These sustainability frameworks support the mainstreaming of triple-bottom-line performance improvements, with an eventual end-goal of 100% less damage, or 'sustainability' [6].

More recent trends towards regenerative development highlight the further evolution of these expectations, although the regenerative field is still emergent [1,2]. With a rapid mainstreaming agenda in mind, and in pursuit of Goal 11 (Sustainable Cities) of the United Nations Sustainable Development Goals (UN-SDGs), it is therefore pertinent to consider how this evolution can be encouraged through the renewal of mainstreaming mechanisms such as industry frameworks and standards [7].

Ecological Performance Standards (EPS) is a performance benchmarking methodology that builds on existing ecosystem services assessment, and that could support the infrastructure sector in shifting towards, and measuring, regenerative performance. It is informed by the field of biomimicry (innovation inspired by nature), which encourages learning from biology and ecology to identify approaches from living systems that may help to address human challenges [8]. The EPS approach looks to nature for guidance on how to measure success and high-functioning performance in the built environment. Using ecosystem system services as a proxy for ecosystem health, this includes investigating how we may design and construct 'built systems' that meet or exceed the functional performance of an ecosystem. While there is limited knowledge regarding 'how' regenerative performance could be integrated into infrastructure, this paper aims to contribute to the body of knowledge exploring how an ecosystem services approach can support infrastructure sustainability schemes to shift towards benchmarking for regenerative performance.

The authors asked: "What is the role of Ecological Performance Standards (EPS) for encouraging regenerative performance in infrastructure"? This included three research objectives, with methods also noted:

- To identify EPS areas where discipline-specific terminology and lexicon were creating barriers to comprehension (Workshop 1).
- To identify opportunities and challenges to integrating EPS into infrastructure practice (Workshop 2–3).
- To create a proof of concept for the EPS method to be applied in infrastructure projects (Mapping and user-case example).

The following paragraphs provide an overview of the evolution of sustainability schemes and frameworks, before introducing the emergent 'Ecological Performance Standards' (EPS) approach to measuring regenerative performance outcomes. The methods and results of academic and industry workshops are then presented and used to map opportunities for using EPS to enable regenerative performance outcomes, including a user-case example, and commentary on implications and next steps. The research demonstrates a clear opportunity to transition beyond 'early efforts' in regenerative performance evaluation, through integrating EPS within existing infrastructure frameworks and standards.

2. Theoretical Background

Consideration of how EPS may apply to infrastructure rests at the nexus of three related trends and practices: (1) evolution of sustainability schemes and frameworks; (2) consideration of ecosystem services within the infrastructure sector; and (3) emergence of EPS as an approach to benchmarking regenerative performance in the built environment. This section provides an overview of the theoretical background underpinning each of these areas, creating a foundation for the research workshops and analysis that bring them together.

2.1. Evolution of Sustainability Schemes and Frameworks

Environmental-, and more recently, sustainability performance evaluation approaches have evolved from traditional approaches of risk-based environmental impact assessments in the 1990s to a variety of triple or quadruple bottom line sustainability rating schemes and frameworks for buildings and infrastructure [9] (see, for example, [4,5,10,11]). Where earlier approaches were focused on the avoidance of material environmental harm, sustainability rating schemes and frameworks are trending towards a more comprehensive set of environmental, social and economic considerations. Performance evaluation objectives have broadened to include the mitigation of indirect sustainability impacts over the asset lifecycle and supply chain, and to reflect broader global political, social and private sector shifts towards sustainable development (including, for example, the United Nations Sustainable Development Goals [12]).

An appreciation of complex trends such as climate change, biodiversity loss and resource scarcity in recent decades has catalysed efforts to reduce negative socio-ecological impacts of built environment design, construction and operation. Global and industry trends towards sustainable development are reflected in the emergence of 'green' and 'sustainable' building and infrastructure rating schemes. As the complexity and scale of these challenges becomes clearer, there are now calls to move beyond damage reduction and risk avoidance, towards transformative 'restorative' or 'regenerative' development [13,14]. Here, the goal is to both avoid damage and to contribute positively to social and ecological systems. If the infrastructure sector is to shift towards regenerative development, it is important that existing industry and government standards and frameworks integrate regenerative performance approaches to support consistency and mainstreaming. In particular, it will require a shift in approaches to both measuring and reporting on sustainability performance.

2.2. Consideration of Ecosystem Services within Infrastructure

Ecosystem services relate to many of the key environmental focus areas currently captured within environment and sustainability tools, frameworks and standards; however, it is rare that these areas are explicitly recognised or managed as ecosystem services. Ecosystem services are the tangible benefits that can be delivered by healthy ecosystems [15]. Aside from delivering advantages to human wellbeing, these services support and can be used as an indicator of ecosystem health. With a focus on interconnected cycles and processes, the concept of ecosystem services largely moves beyond the siloed analysis of environmental impacts and benefits, to reflect dynamic cycles and functions [15].

Across built environment sectors, there has been substantial interest in the potential for aligning existing environmental frameworks and standards with an ecosystem services lens, with a particular focus on environmental impact assessments (EIA) and strategic environmental assessments (SEA) [15,16]. The benefits of this are twofold: first, ecosystem services offer a more comprehensive and integrated perspective on ecosystem performance than traditional environmental parameters (for example, species-based framing). Secondly, the orientation of ecosystem services around tangible human benefit makes it a valuable tool for engagement with communities, decision-makers and other stakeholders [15].

Several assessments have explored the nature and extent of ecosystem services analysis within current EIA practice [15,17]. Baker et al. [15] discuss the benefits of an ecosystem services approach prompting a new lens for understanding the ecosystems under assessment. They highlight the overlap of existing assessment areas such as health and population with cultural ecosystem services including aesthetic value, recreation, cultural and artistic value, spiritual and historic value, and contributions to science and education. Existing considerations of soils align closely with the assessment and measurement of soil formation, while the same can be said for water (water regulation and supply services), and ecosystem services such as nutrient regulation and biological control are very closely tied to existing assessment areas of flora, fauna, air, water and soil, among others.

Honrado et al. [17] similarly point to the alignment between existing EIA coverage and the consideration of ecosystem services. The researchers reviewed twelve processes outlined in EIA reports to identify examples of ecosystem service assessment and gain insight into the current level of alignment. They found examples of ecosystem services quantification across provisioning, regulating, cultural and supporting services. These included, for example, the quantification of project impacts on air quality parameters, calculation of areas to be affected by erosion, soil exposure and bank instability. Ecosystem services of water purification and waste treatment were captured in the quantification and modelling of water quality, and water cycling was captured in cartography on underground infiltration zones, with consideration for vegetation damage and water flow impacts. In terms of people-focused ecosystem services such as recreation and spiritual value, these were captured in cartography and quantification of 'quality-fragility-sensitivity' indices, as well as considerations of camping and access improvements and aesthetic values. Regulation of climate, and food provisioning, among other services, were all captured—and in some formats, quantified—in the EIA reports investigated, highlighting that while EIA are currently not conducted from an ecosystem services perspective, strong foundations exist for such analysis [17].

Using ecosystem services as a primary lens supports the effective framing of the value and benefit offered by ecosystems, allowing stakeholders to more intuitively appreciate the potential impact of a project or development on the ecosystem [15]. On the other hand, it is recognised that ecosystem services assessment may be substantially more resource intensive, particularly where comprehensive baselining is required. Further, ecosystem services categorisations may not align well with all programs, frameworks and standards, in particular where social and community aspects are involved. With this context in mind and appreciating the rapid rise of sustainability frameworks and rating schemes for infrastructure, this paper explores how the consideration of ecosystem services may not only align with infrastructure sustainability schemes but support them in shifting towards benchmarking for regenerative performance.

2.3. Ecological Performance Standards for Regenerative Design

The Ecological Performance Standards (EPS) framework builds on existing approaches to managing ecosystem services; however, with EPS, the boundaries and baselines for measuring performance are shifted. Here, the 'business as usual' baseline is defined by how an intact ecosystem would perform in that place, rather than the current performance of the project site itself, or the anticipated performance of a BAU design [18,19]. This is determined by identifying a local intact ecosystem (onsite or nearby); identifying the ecosystem services generated by that ecosystem type; quantifying the services that would have been generated on the project site if the ecosystem was intact there; and setting these as design parameters and target performance benchmarks. In this way, the project seeks to not only deliver net-positive energy and water, for example, but to support key ecosystem functions and services that would have been generated by an intact ecosystem in that place.

There is now a recognition that maintaining ecosystem services and function creates tangible benefit not only for environmental health and resilience but for human health and wellbeing [20,21]. However, the prioritisation of ecosystem services in urban design and development remains limited, with several challenges to implementation, including a lack of standardised, transferable and generalisable approaches [22]. Various efforts have been made to address this, including important foundational work by Birkeland [23], and efforts to standardise EPS approaches by Pedersen Zari [24], Stack [18], and in teaching and practice by The Biomimicry Center and Biomimicry 3.8, among others. Drawing on these foundations, Figure 1 outlines key steps of the EPS process.

When applying this to a hypothetical infrastructure project on a heavily disturbed site, step one would be to identify a reference habitat. In this example, the project site is not suitable (due to extensive disturbance), so a nearby intact ecosystem is selected as the reference habitat. Next, using available tools/calculators and apps (such as the ESII tool [26]), ecosystem services would be measured, and converted to metrics for the project, e.g., carbon sequestration (amount of CO2-e per area per annum). Drawing on impact assessments, the scale of ecosystem services delivered in the reference habitat, and project objectives, the project team would then prioritise a number of ecosystem services to focus on. Business as usual (BAU) designs would then be used to baseline the extent to which standard design approaches would impact or contribute to those ecosystem services. This would establish the performance gap to be addressed in design. Performance targets could then be established for the project, such as a target of delivering 110 per cent of the baseline carbon sequestration performance through design. Design would be informed by these targets and the ecosystem services could be delivered, for example, through the retention of ecosystems (e.g., tree cover), and/or building and infrastructure design measures (e.g., carbon sequestering materials). Finally, performance would be evaluated against the project targets—first regarding design performance, then in terms of 'as-built' and operational performance.

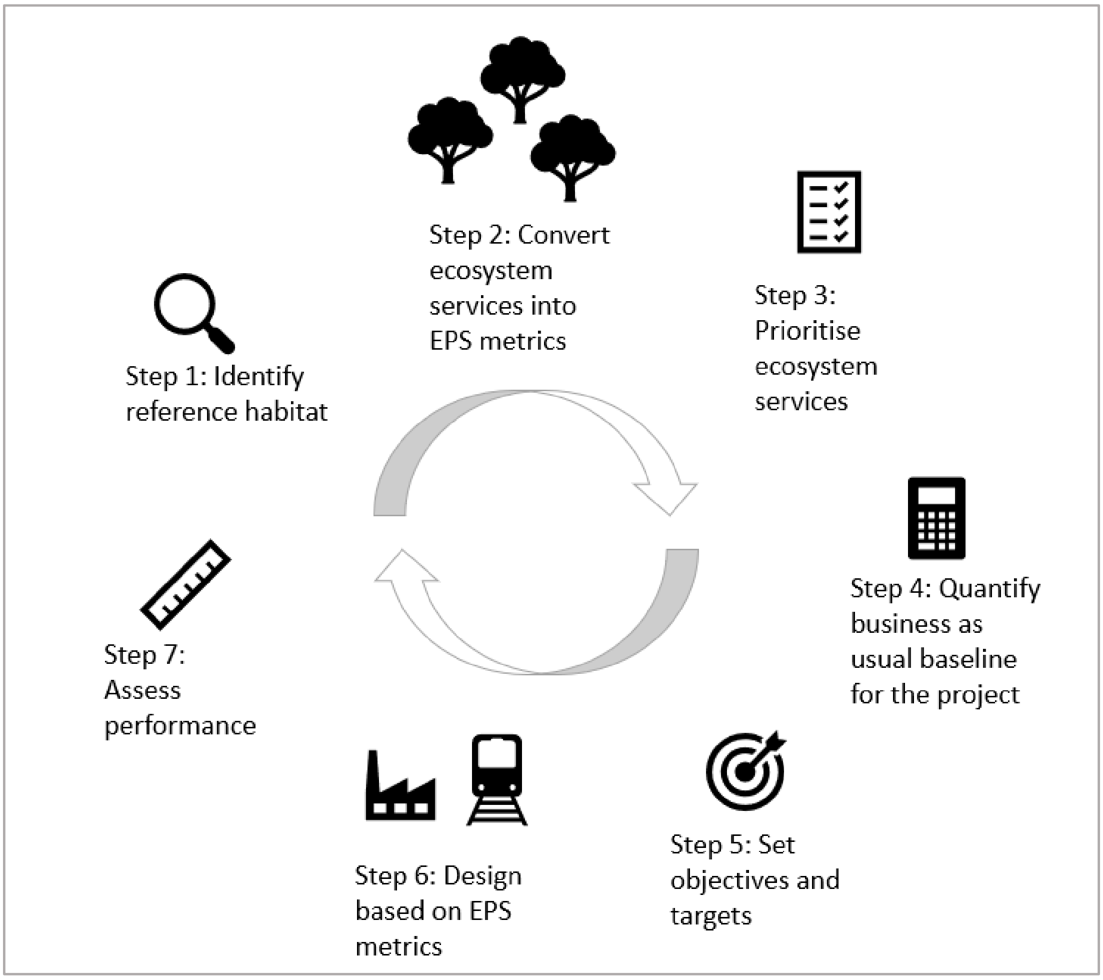

Figure 1. EPS Process steps. Adapted from work by Stack [18], and Interface and Biomimicry 3.8 [25].

The EPS framework promotes the early consideration and evaluation of ecosystem services, as well as ongoing efforts to enhance the delivery of these through built environment design. The goal here is regenerative performance, where the built environment asset delivers the same or greater levels of ecosystem services as an intact ecosystem would in that place. This approach is transformative in three key ways: (a) by setting baseline performance based on an healthy, intact reference ecosystem, rather than the current state of the project site, (b) by allowing for ecosystem performance standards to be met through both ecology and built environment design approaches, and (c) by seeking to achieve net-positive or regenerative performance outcomes.

In early case studies on EPS piloting and other system-level biomimetic design frameworks, several key challenges and barriers emerged [27]. These included scoping and boundaries, knowledge sharing (information availability) and market supply/demand. Other challenges and priority areas included the development of metrics and targets, engagement and education, mainstreaming and the pursuit of sustainability leadership, among others [27]. Table 1 presents a summary of key challenges emerging from biomimicry pilot projects.

Table 1. Key challenges emerging from biomimicry pilot projects.

Key Challenge/Barrier Category	Sub-Categories
Scoping and boundaries	(1) Limited guidance or prior examples of boundaries for quantifying ecosystem services. (2) Limitations regarding the availability of scientific data to inform calculation of EPS metrics. (3) Difficulty creating fixed boundaries within a dynamic ecosystem context.
Knowledge sharing	(1) Lack of prior examples, and (2) availability of scientific data.
Market supply and demand	(1) Limited availability of products, (2) low market capability, and (3) few proven project examples to assist in establishing a business case for uptake and client engagement.

3. Method

Considerations of biomimicry to support regenerative performance in infrastructure are emerging, though they are not widespread [2]. Recent research has systematically reviewed the available literature looking at opportunities for biomimicry in infrastructure, as well as the theoretical foundations for looking to nature when pursuing objectives such as resilience and sustainability [2,28]. Recognising that the literature on system-level biomimicry approaches in the built environment was limited, it was identified that these frameworks were indeed being applied in the private sector, with little analysis, however, in the peer-reviewed literature. As such, six case studies were undertaken that offered insights into current practice and established the foundation for the three research workshops outlined below.

Workshops were deemed appropriate as a targeted method to explore how available system-level biomimicry approaches such as EPS may support objectives of regenerative performance, sustainability and resilience in infrastructure projects through collaborative discussions with key experts.

Workshops are, on one hand, an authentic approach, as they aim to fulfil participants' expectations to achieve something related to their own interests. On the other hand, the workshop is specifically designed to fulfil a research purpose: to produce reliable and valid data about the domain in question [29,30]. The workshops were held in two stages to ensure prolonged engagement with key experts and to address the two research objectives outlined in the introduction [31]. Each of the workshop sessions consisted of a PowerPoint presentation on the current status of biomimicry in infrastructure and details of system-level biomimicry approaches and case studies, which was followed by pre-prepared open-ended workshop activities (i.e., rating of ecosystem services) to engage the participants. Trust was developed through the facilitators' enthusiasm and expertise in the subject matter as well as by interacting with the workshop participants [32]. The facilitators made notes during the workshop and consent was obtained from the participants to use their insights to support the research as de-identified data. Workshop notes and activity sheets were then used to extract and transfer the rich insights of the participants [33] for determining ecosystem service priorities and future opportunities for applying EPS.

3.1. Workshop Setting and Scoping

Building on prior case study research and findings, the methodology consisted of one academic workshop in Phoenix, AZ, USA, and two industry research workshops in Australia (Brisbane and Sydney). With the first workshop focused on harnessing interdisciplinary expertise on biomimicry, design and engineering theory and content, the Phoenix location was selected as the home of The Biomimicry Center, Design School and School of Sustainable Engineering and the Built Environment at Arizona State University. The Biomimicry Center is considered a leader in biomimicry education and process, and one of the early adopters of the EPS approach. The intent of this initial workshop was for multidisciplinary experts to aid in the early identification of EPS 'red flags' or areas where discipline-specific terminology and lexicon were creating barriers to comprehension. The Australian workshops, focused on industry practice, were conducted in the country of the authorship team, with two Australian cities selected to provide perspectives of participants operating under different state legislation and policy.

The focus of the first workshop was to seek feedback on the conceptual foundations of the EPS process by engaging experts from multiple disciplines. The purpose of workshops two and three was to identify challenges and opportunities for the implementation and mainstreaming of EPS in industry and government frameworks for the infrastructure sector. The first academic workshop was conducted with primarily academic participants in the USA, and sought expert feedback on concepts, applicability, conceptual challenges and opportunities. Workshops two and three were conducted in Australia (Brisbane and Sydney) with industry participants to explore mechanisms and strategies for implementation of the EPS in industry and government practice. A summary of participants across the three workshops is provided in Table 2, including the total number of participants from academia and industry at each session.

Table 2. Summary of workshop participants (Academic and Industry).

Workshop Type	Location	Academia Participants	Industry Participants
Academic	Phoenix, AZ, USA	13	2
Industry	data	0	9
Industry	data	1	14
Total		14	25

3.2. Workshop Structure

The workshop process allowed for outcomes from the initial academic workshop to refine the workshop protocol for the industry-focused sessions that followed. The structure is outlined in Figure 2 and expanded below.

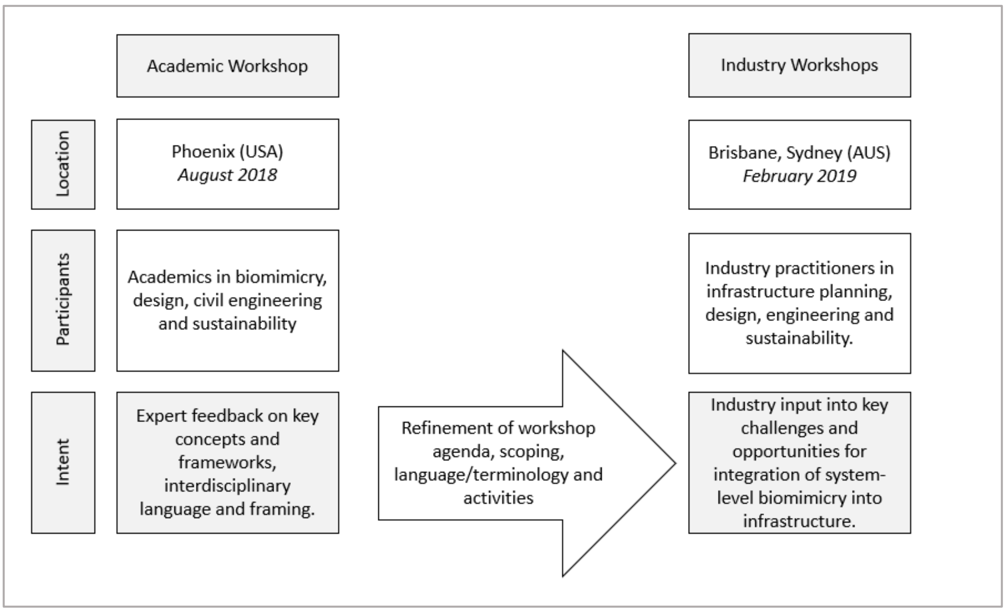

Figure 2. Overview of workshop structure—Academic and Industry workshops.

3.2.1. Stage 1: Academic Workshop (Phoenix, AZ, USA)

An initial exploratory workshop was conducted to seek expert feedback from academics in the field of biomimicry, design, civil engineering and sustainability. In addition to academic participants, two industry participants attended to provide early industry insights into potential challenges and opportunities for integration into practice. The workshop was 2.5 h in duration and conducted in person, with outputs captured as written responses to pre-prepared open-ended workshop activities. Fifteen attendees participated in a structured session that addressed the research context, the biomimicry context (including current status of biomimetic engineering research and application in the built environment), an introduction to three system-level biomimicry frameworks (including the EPS process), and small group discussions with feedback, exploring opportunities and gaps in proposed approaches.

Participants were identified through publications as well as chain-referral or 'snowball' sampling [34], where participants were asked to suggest others within their field who may offer valuable insights. Academic participants at the exploratory workshop included five Associate Professors, three Centre Directors, five student or post-graduate researchers, and one Operations Assistant. Four of those present were from an institute, while six were from a school (department), reflecting a balanced mix of key relevant disciplines and a strong representation from senior academics in their respective fields. Two industry participants were also involved, with one Architect and one Biophilic Designer present. Following the workshop, hardcopy activity responses were collated and summarised for analysis.

In exploring the integration and mainstreaming of the EPS approach in the infrastructure, participants worked in groups of up to six people to identify (1) primary opportunities for the integration of the EPS approach, including key potential benefits, and (2) key challenges and barriers to uptake. These were captured as hardcopy responses before being shared with all workshop participants to prompt further interdisciplinary discussion regarding challenges and opportunities for adoption. The findings of the academic workshop were used to refine the workshop agenda, scoping, language and activities prior to the industry workshops that followed.

3.2.2. Stage 2: Industry Workshops (Brisbane and Sydney, Australia)

Two workshops were conducted in Australia (Brisbane and Sydney), with the intent of seeking input from industry stakeholders to identify opportunities and challenges to integrating system-level biomimicry into infrastructure practice. Participants were industry practitioners specialising in infrastructure planning, design, engineering and sustainability. Each workshop was approximately 2.5 h in duration and conducted in-person, with outputs captured as written responses to pre-prepared workshop activities. There were 9 attendees at the Brisbane workshop and 15 at the Sydney workshop. Participants were practitioners involved in infrastructure sustainability, project delivery, design and engineering. Participants were again identified through publication searches and chain-referral or 'snowball' sampling [34]. An invitation was also published by the lead author on LinkedIn to draw on industry networks in the field. Following the workshop, activity responses were collated and summarised for individual workshops and then as combined outputs.

The workshops were conducted as structured sessions addressing an overview of the current status of biomimetic engineering research and application in the built environment, an introduction to three system-level biomimicry frameworks (including the EPS process), and structured activities exploring opportunities and challenges for the uptake of the three frameworks. For the purpose of the workshop activities, the EPS process was divided into seven steps, as outlined in Figure 1 above. During the workshops, two EPS-focused activities were completed by workshop participants, with participants in working groups (WG) of three to six people to complete each activity.

Activity 1 was designed to identify current industry approaches to managing, generating and measuring ecosystem services in infrastructure design, construction and operation. Participants were asked to consider a list of 18 ecosystem services and identify:

1. The extent to which each ecosystem service is addressed and delivered by current industry approaches (1–5, with 1 = Never and 5 = Always).
2. The frameworks and schemes that address each ecosystem service, including those that prompt or enable action.
3. Specific examples of controls and initiatives used to manage/deliver those ecosystem services on infrastructure projects.
4. A prioritisation ranking of the perceived importance of each ecosystem service to project performance.

This provided insights into current practice, knowledge gaps, and alignment with existing regulations and voluntary frameworks. The second activity was structured around the seven EPS process steps outlined in Figure 1, namely: (1) identify reference habitat, (2) convert ecosystem services into EPS metrics, (3) prioritise ecosystem services, (4) quantify BAU design baseline, (5) set objectives and targets, (6) design based on EPS metrics, and (7) Assess performance.

Participants were asked to map these process steps to the key phases of the infrastructure/building project lifecycle: Planning, Design, Construction, Operation and Decommissioning. Next, they again identified frameworks and schemes that could prompt or support the achievement of that process step during each phase. Finally, to highlight early opportunities for adoption and integration, participants were asked to identify 'entry level' opportunities for implementation. This involved proposing ways in which early adopters of the EPS approach could introduce relatively minor adjustments to existing processes and practices to begin introducing and integrating EPS into industry and government practice.

3.3. Data Analysis

Results from the academic workshop were consolidated and reviewed for key themes relating to the EPS framework and its potential for integration into infrastructure practice. The opportunities and challenges that were identified prompted a more direct focus on the integration of EPS into existing frameworks in the industry workshops, including opportunities for supporting mainstreaming through pilot projects, knowledge sharing and the standardisation of metrics and process.

For the industry workshops, responses from each working group were captured on hardcopy activity sheets before being transcribed in Excel. Responses to each activity were then aggregated across working groups, and then across both workshops to identify key emerging themes. Scores from activities involving rankings were averaged across the workshops to generate an average ranking out of 5 for each ecosystem service. These were then averaged again to provide an overall score for each ecosystem service category (supporting, regulating, provisioning and cultural) from a total possible score of 5.

Exploring the potential for EPS integration, following the workshops the lead author undertook a full review of the IS Rating Scheme (Version 2.0, Design and As-Built), to identify where ecosystem services are already partially captured within existing credits of the rating scheme.

4. Results

Results from the academic workshop (conducted in the USA) included the identification of opportunities and challenges to the uptake of the EPS approach, as well as barriers associated with interdisciplinary engagement such as language and lexicon. The industry workshops (conducted in Australia) generated a more detailed consideration of potential implementation pathways and approaches. Findings from the first workshop were used to assist in framing for the latter sessions. For the industry workshops, results first reflected on the current perceived level of performance in protecting and generating ecosystem services, followed by opportunities for integrating the EPS process into future projects.

4.1. Academic Workshop

Participants identified opportunities including the potential for EPS to add to the robustness of sustainability assessments and lifecycle assessment, as well as expanding the boundaries of what is currently considered within such assessments. This creates potential for a paradigm shift that moves beyond incremental improvements yet leverages existing practice and capability. Participants noted the opportunity for EPS to be used as "a framework for monetary cost-benefit analysis" (WG1) and proposed pilot projects for testing and refinement.

Workshop participants also suggested several potential barriers to implementation. They noted that while EPS expands the approach to environmental assessment, it remained a necessarily "reductionist approach" (WG1) that reduced environmental function to a selection of metrics. They noted limited existing incentives for implementation, limitations to the availability of data, emerging quantification methodologies and approaches to "deal with trade-offs between variables" (WG3), as key potential challenges that may be faced in implementation. More broadly, they referenced hurdles associated with education and understanding, including challenges with "interdisciplinary communication" (WG2) and frameworks. Participants referred to the need for pilot projects to demonstrate success and offer "proof that these work on a system level" (WG1), the need to capture social and economic aspects of sustainability (including through cost-benefit analysis) and, importantly, the availability of tools and applications to support quantification. Recommendations included the need to integrate with existing systems, the important role of standards and legal design requirements, and the necessity of an "anchor client" (WG3) to catalyse action.

4.2. Industry Workshops

The industry workshop activities were designed to explore how the EPS framework may be applied in industry and government, and to identify key leverage points in existing practice and frameworks. The results cover two perspectives: (1) ecosystem services performance and (2) the EPS process. For the former, activities investigated how specific ecosystem services are currently protected or enhanced on infrastructure projects by industry and government practice, to what extent this is done, and what frameworks and standards may support such outcomes. For the latter, activities explored how each step of the EPS process may reasonably be delivered, at which project phase they would be most applicable, and with what frameworks and standards they may align. Key outcomes from these workshop activities are summarised below.

4.2.1. Ecosystem Services Performance

Across 18 ecosystem services (drawn from [35]), workshop participants ranked the extent to which they believed each service was currently supported by industry practice. This assessment of current practice offers an indicative insight into the current level of consideration of ecosystem services within the infrastructure sector. Where current practice is well established and the sector has developed processes and controls for measuring and managing an ecosystem service, the transition to an EPS approach is likely to be more manageable. This includes developing EPS metrics (Step 2), prioritising ecosystem services (Step 3), quantifying BAU impact (Step 4) and assessing performance (Step 7). This work provides the first step in addressing the transition to an EPS approach, through setting the local reference framework.

Table 3 summarises working group responses averaged across the two workshops, with 1 indicating the highest ranked performance, and 18 reflecting the poorest ranked performance. Overall, participants ranked flood mitigation, erosion control and waste minimisation as the top three ecosystem services addressed by current practices. Pollination and seed dispersal, carbon sequestration and spiritual inspiration were highlighted as the services least supported by current practice and approaches.

Table 3. Ecosystem services—participant rankings of current industry performance.

Ecosystem Services	Rank
Mitigation of Flood	1
Erosion Control	1
Waste Minimisation	1
Moderation of Noise	4
Aesthetic Value and Artistic Inspiration	5
Biodiversity Retention	6
Purification of Water	6
Purification of Air	6
Habitat Provision	9
Education and Knowledge	10
Soil Formation and Retention	11
Recreation, Relaxation and Psychological Wellbeing	12
UV Protection and Temperature Moderation	13
Generating Energy	14
Food (Human and Wildlife)	15
Pollination and SeedDdispersal	16
Carbon Sequestration	17
Spiritual Inspiration	18

Top three ranked are shown in bold, and bottom three ranked shown in italics. List of ecosystem services adapted from Pedersen Zari [24].

For the top three ranked services, workshop participants provided detailed notes on the current measures and initiatives typically adopted, as well as the related frameworks and standards that support or catalyse action. For flood mitigation (ranked first), frameworks and standards included planning approvals, flood level limits (e.g., 100-year average return interval), regulatory requirements including erosion and sediment control (ERSED), Infrastructure Sustainability (IS) Rating Scheme Version 1.2 Credits including 'LAN4-Flooding', and rainfall and runoff guidelines.

For erosion control, frameworks and standards spanned legislated state planning policies, state and local council guidelines and specifications, and the IS Rating Scheme Version 1.2 'DIS1-Receiving water quality' credits. For waste minimisation, frameworks and standards consisted of legislated waste management requirements, IS Rating Scheme Version 1.2 Waste Credits, business as usual expectations, deed requirements and targets, and financial implications.

For the bottom three ranked services, workshop participants also highlighted control measures and relevant frameworks and standards, where applicable. For pollination and seed dispersal (ranked third lowest), frameworks included client targets, approvals, EIS-driven seed collection and landscaping requirements. For carbon sequestration (ranked second lowest), frameworks included project criteria, carbon offsetting requirements, the national carbon offset standards, the IS Rating Scheme and other contract requirements, as well as the federal carbon reduction fund. For spiritual inspiration (ranked lowest), there was recognition of IS Rating Scheme Heritage elements, as well as the role of reconciliation action plans.

Reflecting the results from another perspective, Table 4 displays the list of ecosystem services as provided to participants, where column one lists the ecosystem service category (i.e., supporting, regulating, provisioning or cultural), and column two lists the ecosystem service name. The third column reflects the average of scores for each working group (3–6 participants), where groups were asked to score based on their perceptions of industry practice broadly. Scores were recorded from 1 to 5, where 1 reflected services that are 'never' currently addressed, and 5 indicated services that are 'always' currently addressed. In column four, these have been averaged to provide an overall score for each ecosystem service category (supporting, regulating, provisioning and cultural). This provides early indications of the extent to which current practices and frameworks in the infrastructure sector are managing and contributing to ecosystem service performance.

Table 4. Average participant working group scoring of performance against each ecosystem service.

Ecosystem Service Category	Ecosystem Service Name	Perceptions of Current Industry Performance (1 = Never Addressed, 5 = Always Addressed)	Average Score for Ecosystem Service Category
Supporting services	Habitat provision	3.63	3.24
	Biodiversity retention	3.75	
	Soil formation and retention	3.58	
	Carbon sequestration	2.00	
Regulating services	UV protection and temperature moderation	3.40	4.39
	Mitigation of flood	5.00	
	Erosion control	5.00	
	Waste minimisation	5.00	
	Purification of water	3.75	
	Purification of air	3.75	
	Moderation of noise	4.80	
Provisioning services	Generating energy	3.25	2.81
	Pollination and seed dispersal	2.30	
	Food (human and wildlife)	2.88	
Cultural services	Education and knowledge	3.60	3.21
	Aesthetic value and artistic inspiration	4.00	
	Recreation, relaxation and psychological wellbeing	3.50	
	Spiritual inspiration	1.75	

Table 4 shows that regulating services were ranked highly with an overall average of 4.39, while provisioning services were ranked lowest at 2.81.

In terms of the frameworks and standards that support the delivery of these ecosystem services, participant responses spanned a wide range of policies, frameworks, rating schemes, regulations and other drivers for the action and management of ecosystem services. Importantly, the Infrastructure Sustainability (IS) Rating Scheme was highlighted by respondents as a primary enabling mechanism for the management and delivery of 14 of the 18 ecosystem services. Legislation and regulation were referenced for 9 of the 18 services, and other guidelines and standards were referenced for 8.

4.2.2. EPS Process

The workshop activities then explored the EPS process steps described in Figure 1, asking participants to identify where in the infrastructure lifecycle phase each step would be ideally undertaken. These results are reflected in Figure 3.

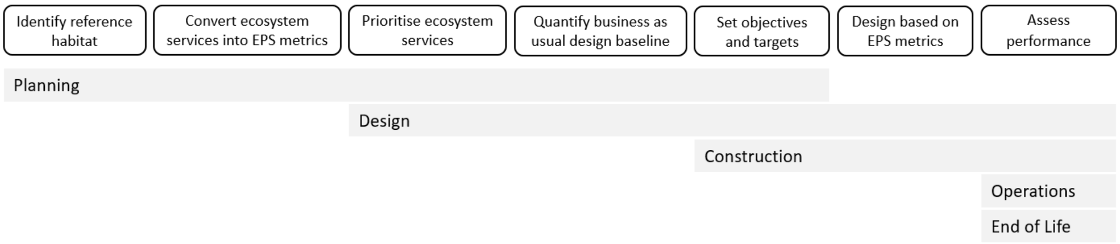

Figure 3. EPS Process steps and associated project phases.

In the planning phase, the priority process steps identified were: identify reference habitat, convert ecosystem services to EPS metrics, prioritise ecosystem services, and set objectives and targets. At the design phase, the priority was to further prioritise the list of ecosystem services and select a subset of services to focus on, to quantify the business-as-usual design baseline, refine objectives and targets, and design based on the EPS metrics. This also included some assessment of projected performance against the design objectives. For construction, the priorities were to assess performance, and to a lesser extent, to set and refine objectives and targets, and to design based on EPS metrics. In operation, the focus was on assessing performance, and at end of life there was a continued yet decreasing prioritisation of performance assessment.

Participants were then asked to brainstorm feasible and practical 'entry-level' approaches to completing each of the seven EPS process steps. Recognising that the process can be highly unique and innovative, it may not be feasible for project teams to implement each step to its fullest and most comprehensive extent in early iterations. As such, this activity sought to highlight early steps that industry and government may take to initiate the piloting and implementation of the EPS process.

Recommendations for entry-level approaches to the EPS steps primarily involved alignment with existing processes, standards and requirements. Participants noted opportunities to leverage tender processes, as well as risk and opportunity assessments to capture EPS requirements. A bill of quantities and design reports could support baselining, for example, while objectives and targets could be developed in line with international standards for quality and environmental management. Green building and infrastructure schemes offer opportunities to catalyse performance improvement and existing monitoring and verification processes may be leveraged to support ongoing evaluation. In addition, the activity asked participants to highlight frameworks and standards that may support the implementation of each step of the EPS process. A summary of key results is captured in Table 5.

In terms of overarching frameworks and standards, environmental impact assessment (EIA) emerged as a key reference framework, particularly in early phases. Opportunities to leverage the Infrastructure Sustainability (IS) Rating Scheme were raised by participants for every stage of the EPS process. Additionally, legislative requirements, procurement and construction processes, and environmental management standards were also referenced.

Across each of the workshops and within each working group, responses consistently pointed to sustainability rating schemes as an optimal leverage point for introducing EPS into existing industry and government practice.

4.3. EPS Mapping for a Typical Infrastructure Project

Exploring this potential, a full review of the IS Rating Scheme (Version 2.0, Design and As-Built) was conducted to identify where ecosystem services are already partially captured within existing credits of the rating scheme. Table 6 maps the 18 ecosystem services against the IS Rating Scheme credits and categories, summarising where ecosystem services are addressed within the current scheme.

Table 5. EPS Process—Entry-level approaches, and frameworks and standards aligned to adopting Ecological Performance Standards.

EPS Process Steps	'Entry-Level' Approaches For Introducing Ecological Performance Standards into Current Practice	EPS Process Steps
Identify reference habitat	• Include ecosystem services in existing environmental impact assessments (EIAs)—reference habitat can be identified as part of this process.	• EIA and supporting legislation
Convert ecosystem services into EPS metrics	• Commission an expert assessment to identify/develop appropriate metrics for measuring ecosystem services for that project. • Develop qualitative design guidelines in lieu of quantitative performance metrics	• Returnable schedules (i.e., in tenders with high weighting) • EIA's • Sustainability Rating Scheme credits (leveraging and extending on existing foot-printing and measurement requirements) • Legislation amendments • Materials specifications
Prioritise ecosystem services	• Insert new category into sustainability rating schemes focused on ecosystem services, including process for prioritisation. • Focus efforts on ecosystem services that align with client/project priorities, as well as compliance and contractual requirements. • Prioritise ecosystem services using existing risk management processes and workshops.	• Align with green building challenge and sustainability tools • Client requirements/targets • Government/Sustainability Rating Scheme requirements • Sustainability Rating Scheme weighting assessment
Quantify business as usual design baseline	• Use bill of quantities and design reports to model/estimate the ecosystem services impacts of business-as-usual design. • Calculate BAU performance only for the top 2–3 prioritised services.	• Bill of quantities • Construction methodology • IS Rating Scheme requirements • EIA and Sustainability Rating Scheme (BAU Assessment) extending the base case
Set objectives and targets	• Align with contract requirements and key standards (e.g., ISO 9001, ISO 14001) • Use risk assessment process to identify priority aspects and integrate into project deliverables • Engage with stakeholders • Allow for flexibility (e.g., frame as ambitious or 'Stretch' targets)	• Contract • Sustainability Rating Scheme targets • Legislation and best practice docs • ISO9001 and ISO14001 (including continuous improvement)
Design based on EPS metrics	• Industry, government and academia collaborate to develop EPS design guidelines to assist organisations. • Align with and leverage 'green' rating schemes and frameworks, so that these may guide projects in how to design for EPS. • Encourage incorporation of EPS metrics into government policy and planning documents.	• Construction methodology • Sustainability Rating Scheme targets and requirements • Project management plan • Design specifications • EIA • Green building schemes and frameworks
Assess performance	• Early adopters and leaders in industry to pilot and share results. • Begin to measure performance against EPS metrics, even if not yet introducing design responses. • Use existing processes, e.g., test plans, inspection verification and monitoring to assess impact.	• Self-development and assessment • Sustainability Rating Scheme and contract requirements • ISO 14001, ISO14011—audits and inspections; compliance agencies

Table 6. Examples of current consideration of ecosystem services within the IS Rating scheme.

	IS Rating Scheme (V2.0 Design and As-Built) Categories																
	Governance					**Economic**		**Environment**						**Social**			
	Context	**Leadership and Management**	**Sustainable Procurement**	**Resilience**	**Innovation**	**Options Assessment and Business Case**	**Benefits**	**Energy and Carbon**	**Green Infrastructure**	**Environmental Impacts**	**Resource Efficiency**	**Water**	**Ecology**	**Stakeholder Engagement**	**Legacy**	**Heritage**	**Workforce Sustainability**
Ecosystem services																	
Supporting Services																	
Habitat Provision		X	X	X						X			X				
Biodiversity Retention			X			X			X				X		X		
Soil Formation and Retention									X	X	X						
Carbon Sequestration			X					X	X								
Regulating Services																	
UV Protection and temperature moderation				X					X	X					X		
Mitigation of Flood		X		X					X								
Erosion Control										X		X	X				
Waste Minimisation								X			X						
Purification of Water									X	X	X	X					
Purification of Air									X	X							
Moderation of Noise									X	X							
Provisioning Services																	
Generating energy				X		X	X	X									
Pollination and seed dispersal																	
Food (human and wildlife)									X								
Cultural Services																	
Education and knowledge		X			X	X									X	X	X
Aesthetic value and artistic inspiration	X					X			X	X				X	X	X	
Recreation, relaxation and psychological wellbeing	X								X	X		X			X		X
Spiritual inspiration	X		X						X					X		X	X

The below discussion expands upon these early findings and recommendations, proposing actionable pathways for achieving this.

5. Discussion

This section explores opportunities for incorporating the EPS methodology into sustainability frameworks for infrastructure, to leverage existing efforts and support a shift towards regenerative performance standards. Building on key findings from the academic and industry workshops, and learnings from early biomimetic pilot projects, it recognises the important role of frameworks and standards in mainstreaming emerging infrastructure approaches and outlines pathways for integrating ecosystem services and the EPS process into infrastructure rating schemes.

5.1. Opportunities for Standardisation and Integration

Standardisation provides opportunities for consistency and widespread uptake, by leveraging existing frameworks that reflect industry best practice and innovation. Looking to the challenges faced by system-level biomimicry pilot projects to date (Table 1), scoping and boundaries, knowledge sharing, and market maturity arose as key barriers to implementation and mainstreaming [27]. Setting a consistent scope for EPS efforts through mainstream standards and frameworks can support capability building and consistency across projects, and over time, reduces the uncertainty associated with scoping and boundaries at the project level. Market maturity, another key challenge, is supported by the increased uptake of the EPS process across industry, as catalysed by its inclusion in such frameworks. Finally, knowledge sharing is supported both by explicit requirements incorporated into rating schemes (i.e., IS Rating Scheme knowledge sharing requirements), and through the requirements for communicating EPS performance and targets across project phases.

Despite these potential benefits, there are limitations and potential negative repercussions that may arise from standardisation. For scoping, while standardisation may make scoping easier and more consistent, this may not allow for scoping adjustments based on project-specific variables and ecosystem and project characteristics. Ultimately, in the pursuit of standardisation and consistency, there is a risk that an overly reductive or narrow approach to scoping may be adopted, or in the other extreme, that project scoping may lead to an excessively arduous ecosystem services assessment task. Standardisation may also limit creativity, flexibility and adaptability—important attributes of innovation in complex systems.

'Locking in' specific approaches to ecosystem services assessment and EPS may lead to path dependency and limit opportunities for the further testing and refinement of EPS approaches, a risk that is particularly pertinent for emerging areas where practice is not well established and tested. To address these risks, some rating schemes have opted for more flexible approaches to incorporating emerging concepts, where the scheme outlines the proposed framework or tool, and allows project teams freedom to determine the extent and nature of implementation. By not strictly dictating process and methodology, this approach allows for practitioners to pilot a range of approaches to utilising the framework that creates a portfolio of potential approaches.

Figure 4 portrays key opportunities for the integration of (a) the EPS process and (b) ecosystem services performance into sustainability rating schemes for infrastructure. The following sections elaborate on key mechanisms (presented in white boxes) to enable the purposeful integration of EPS into sustainability rating schemes.

5.2. Incorporating EPS into Sustainability Rating Schemes

The proposed approach to integrating EPS is through existing infrastructure sustainability rating schemes such as CEEQUAL, Envision, IS Rating Scheme and the Living Community Challenge [4,5,10,36]. While these schemes vary in structure and scoping, categories and content have many alignments. Content developed for one scheme could be largely transferrable to other schemes with minor adjustment, including building sustainability rating schemes such as Green Star and LEED [11,37].

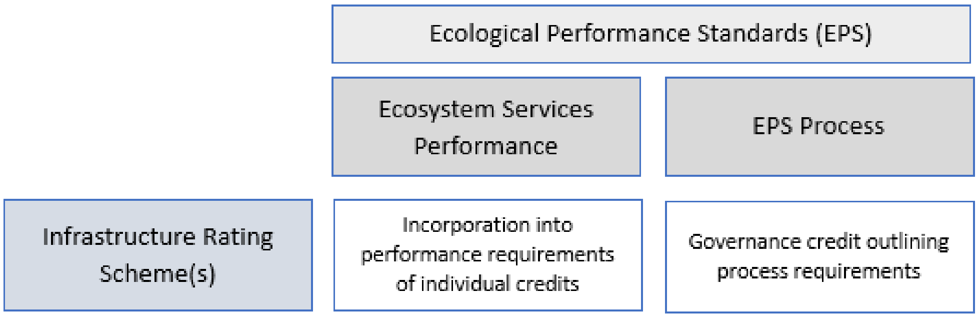

Figure 4. Opportunities for incorporating the Ecological Performance Standards (EPS) approach into sustainability rating schemes.

Two mechanisms are proposed for integrating EPS into existing schemes, namely via: (1) an overarching governance credit (articulating the EPS process steps and approaches to benchmarking ecosystem services for the project), and (2) embedding EPS within other credits or topics throughout a rating scheme (where specific ecosystem services could be assessed and managed as a component of individual credits for energy generation or waste management, etc.). Given that the IS Rating Scheme was repeatedly referenced as an enabling framework in the workshop results, for this paper we focus on that scheme to explore how ecosystem services performance, and the EPS process, may be integrated. Beyond the IS Scheme, it is anticipated that these approaches could readily apply to other international infrastructure and building sustainability schemes.

5.2.1. Creating an Overarching Governance Credit for EPS

Under the IS Rating Scheme (Version 2.0) [4], the 'Governance' theme establishes the overarching sustainability governance approach for the project through planning, design, construction and operation. These credits create the framework for key governance elements across the project, including leadership and management, sustainable procurement, resilience, and innovation. It is this type of overarching credit to which the EPS process may similarly be well suited, where a governance credit outlines requirements and guidance for implementing each of the seven steps of the EPS process.

When looking to introduce new credits into sustainability rating schemes, a common approach has been to first leverage the 'Innovation' credits common in such schemes. In the IS Rating Scheme (V2.0), the Innovation credit (Inn-1) recognises innovative approaches to industry and project challenges by rewarding: (a) State/National/World 'firsts' (where an innovative technology or process is implemented for the first time), (b) market transformation activities, (c) improvements on existing credit benchmarks, and (d) targeted innovation initiatives aimed at addressing recognised industry-wide challenges. Through these streams, the credit offers several opportunities to introduce innovative approaches. In the IS Scheme, the innovation credit has also been used specifically to pilot drafted or proposed new credits—an opportunity for the introduction and testing of an EPS process credit within the sustainability rating scheme.

5.2.2. Embedding EPS within Existing Credits

In addition to the above, there are opportunities for EPS to be incorporated into sustainability rating schemes, with minimal tweaks to the content and benchmarks of existing credits. Many existing credits, both within the IS scheme and across similar sustainability rating schemes, cover content that aligns closely with ecosystem services and goes some way towards satisfying the EPS approach. For this reason, it is pertinent to consider opportunities for adjusting existing rating scheme credits to align monitoring and performance approaches with the EPS framework.

Table 6 highlights the connectedness between the existing IS Rating Scheme and the consideration of ecosystem services. For some credits, the existing benchmarking and performance requirements of the rating scheme are already somewhat aligned with those of an EPS approach. IS Rating Scheme credits relating to discharges to air and water, as well as noise impacts, for example, require baseline monitoring as well as ongoing measurement and evaluation of performance (Env-1, Env-2, Env-4). For these credits, pursuing net-positive ecosystem services may simply require (a) using an intact local reference ecosystem for baselining and benchmarking purposes if the project site does not qualify, and (b) pursuing a net improvement in performance relative to the baseline, either through ecological or manmade solutions. While other credits may require greater adjustment, many of the categories highlighted above already make helpful progress towards maintaining ecosystem services, though often without recognition or articulation of such. The introduction of an EPS approach could leverage this existing effort into a unified approach to regenerative infrastructure performance.

With this foundation, the authors conclude that the EPS process offers an opportunity for industry and government to leverage existing efforts in pursuit of regenerative performance outcomes, with minimal additional effort or resourcing required. Moving forward, there are likely to be several other valuable opportunities for the integration and mainstreaming of this EPS approach, including integration into emerging frameworks and indices, such as the Recommendations of the Taskforce on Climate-related Financial Disclosures (TCFD) [38], the Dow Jones Sustainability Index (DJSI) [39], the Carbon Disclosure Project [40] and other similar frameworks for evaluation and reporting.

6. Conclusions

Emerging discussions around regenerative development have not yet influenced mainstream design and engineering approaches in infrastructure. If regenerative performance is to become an actionable goal for the sector, it will be important that such goals are captured within mainstream industry and government standards and frameworks, to enable consistency in scoping and guidance, and to encourage knowledge sharing and sector-wide capability building. Though regenerative development concepts and associated mechanisms are relatively recent in an infrastructure context, environmental and sustainability frameworks and standards are increasingly well embedded within mainstream business as usual practice. As such, these frameworks offer a logical leverage point for introducing regenerative development approaches for infrastructure projects. Key stakeholders such as designers, architects, builders, construction managers, and engineers from the built environment sector would directly benefit from these frameworks.

The Ecological Performance Standards (EPS) approach looks to nature for guidance in setting regenerative performance standards for the built environment. Instead of asking 'How can we reduce the negative environmental and social impacts of our project relative to BAU approaches?', the EPS approach moves beyond damage mitigation and towards net-positive performance. Under this approach, the question becomes 'How would an ecosystem perform here (as measured by ecosystem services generation), and can our constructed asset meet that same performance standard?'.

This paper proposed two key pathways for integrating the EPS framework into infrastructure sustainability rating schemes, first as a governance credit, and then as an expanded consideration of ecosystem services throughout the schemes, to support a shift towards regenerative performance standards. The authors aligned the EPS process steps to key infrastructure lifecycle phases and presented a comprehensive matrix mapping ecosystem services against the IS Rating Scheme to highlight where ecosystem services are addressed within the current scheme. This work is the first of its kind to investigate and map the opportunity for EPS to be adopted within existing infrastructure sustainability frameworks.

We conclude that while the study sample is limited to the local context in Australia with the additional context of the USA, we still find notable unique contextual opportunities for incorporating the Ecological Performance Standards (EPS) approach into sustainability rating schemes. These examples are not intended to be exhaustive, as the purpose of conducting this study was to draw on unique examples and generate deeper insights into a transformed approach for benchmarking the performance of 'sustainable' infrastructure. Opportunities exist for future research to pilot the EPS approach for infrastructure projects, including qualitative and quantitative evaluations of effectiveness. It would also be beneficial to explore challenges and opportunities from a broader range of private and public sector perspectives, including a focus on adoption by government stakeholders. By proposing mechanisms for integration of EPS into industry frameworks, this paper creates opportunities for immediate uptake by practitioners, industry associations, government and academia.

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