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Prevalence of Sustainability concepts in Civil and Environmental Engineering Programs in Australia

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ABSTRACT

CONTEXT
As sustainability becomes an increasingly important issue in Civil and Environmental Engineering, there are growing expectations for graduates to have a thorough understanding of this field. However, integration of sustainability concepts presents challenges for engineering education professionals who may face barriers such as inability to translate sustainability principles into existing subject matter, limited time for incorporation into curricula, already crowded curricula, and lack familiarity with social sciences and humanities perspectives.

PURPOSE
This paper presents the results of a mapping exercise into the integration of sustainability concepts in core and elective courses from five highly ranked Australian universities offering four-year Engineers Australia accredited Bachelor of Engineering degrees in Civil or Environmental Engineering as of 2021. The aim is to identify at a high level how sustainability is currently addressed in core and elective courses for the different degrees at different universities. This will enable best practice as well as opportunities for improvement to be identified.

APPROACH
Degree structures and individual subject handbook entries or course profiles were compiled for both Civil and Environmental degrees from five universities in Australia. These documents were reviewed for key words related to “sustainability” and the prevalence of these terms in core and elective courses were recorded along with general themes in which sustainability was presented. A more in-depth investigation into how sustainability concepts were integrated was also conducted for both degrees at UNSW Sydney.

OUTCOMES
Outcomes from the review identified a need for consistent definitions of sustainability throughout programs and scaffolded throughout year levels. Opportunities for horizontal integration could involve case studies and discussions of the roles of engineers in our changing world.

CONCLUSIONS
Overall, this paper emphasizes the importance of reviewing and updating engineering curricula to better incorporate sustainability principles. Many programs need an overlying sustainability vision, within which courses can orientate their sustainability content. This has advantages in scaffolding content throughout degrees, ensuring clear and consistent use of terminology and establishing efficiencies in already constrained curriculums. By doing so, graduates will be better equipped to tackle the complex challenges facing society and the environment in the 21st century, as Civil and Environmental Engineers are building our future now.

KEYWORDS
Curriculum mapping, Sustainability principles

Introduction

Sustainability is an increasingly important theme to teach in engineering degrees, such as Civil and Environmental Engineering, due to graduates' roles in preparing the physical world and infrastructure for the future. However, sustainability is more than just minimising direct environmental impacts, necessitating multidisciplinary approaches and broader discussions beyond solely pollution reduction or carbon footprint minimization.

Accreditation bodies now demand engineering graduates to demonstrate fluency and experience in sustainability. Figure 1 shows the broad range of areas in which sustainability concepts are thought to be relevant to Civil and Environmental Engineering practice. The EA code of Ethics emphasizes engineers' responsibility to act sustainably (Figure 1), as does the Sustainability Policy and EA competencies (1.5 b and 1.6 c) (EA Sustainability Steering Committee, 2017; Engineers Australia, 2022; Hoffman, 2013).

The pressing need for shifting paradigms addressing finite resources and environmental degradation underscores the need for educational institutions to rethink curricula to align with sustainable development (Davidson et al., 2007). Sustainability mapping in curriculums is not a novel concept, having first been documented by Hall and Barger (1998). Examples of previous studies include those focused on other programs such as chemical engineering (Bury et al., 2022), civil and environmental engineering programs overseas (Christ et al., 2015), case studies at one particular university (Daniell & Maier, 2005), or focusing on specific courses or year groups (Rose et al., 2015). Key challenges in adopting this curriculum change identified by (Davidson et al., 2007) are slow changes in educational institutions, challenges in defining sustainability, and managing the large educator workforce who are delivering content. The continued interest in this topic almost 30 years since it was first documented belies this. Our paper's novelty lies in its focus on a range of G08 universities in Australia currently offering Civil and Environmental engineering programs.

Examples of Engineering Practice

- Planning and approvals (impact assessment of environmental and social hazards)
- Design and buildings (efficiency, material choices, rating tools) and infrastructure (sustainable transport systems).
- Project Delivery (environmental protection, social and economic considerations)
- Management of projects and companies (operational efficiencies, management systems, monitoring, auditing, sustainability reporting)
- Stewardship (end of life/waste management, deconstruction, remediation)

*"**4 Promote sustainability***

4.1 Engage responsibly with the community and other stakeholders

4.2 Practise engineering to foster the health, safety and wellbeing of the community and the environment

4.3 Balance the needs of the present with the needs of future generations"

Figure 1: (left) Dimensions of sustainability practice as judged relevant to Civil and Environmental Engineering, (right) Excerpt from the Engineers Australia Code of Ethics (EA Sustainability Steering Committee, 2017; Engineers Australia, 2022)

Methodology

Sustainability mapping for different courses

The study used manual term analysis of 'sustainability' or "sustainable' in the publicly available handbook entries or course outlines to identify courses likely to include sustainability concepts. A similar approach was used by Bury et al. (2022) for a chemical engineering program. Course particularities such as level, school, and where sustainability was mentioned, e.g. in the course descriptions or course (or subject) learning outcomes (CLOs), were also noted. Core subjects as well as discipline electives were reviewed.

Bachelor of Engineering (Honours) programs with standalone specialisations in Civil or Environmental Engineering from a selection of Group of Eight (G08) universities were reviewed (Table 1). Only programs which in 2021 had a ranking in the top 150 according to Shanghai rankings were included (G08, 2021).

Table 1: Compilation of Bachelor of Engineering programs with specialisations in Civil or Environmental Engineering included in this study. A '+' was used to indicate if sustainability was mentioned in the overall program description.

University	Code	Civil Engineering	Environmental Engineering
The University of Adelaide	Adelaide	Reviewed **+**	Reviewed **+** [1]
Monash University	Monash	Reviewed	Reviewed **+**
UNSW Sydney	UNSW	Reviewed	Reviewed
University of Sydney	USYD	Reviewed	- [2]
The University of Western Australia	UWA	- [2]	Reviewed **+**

1. Bachelor of Engineering (Honours)(Environmental and Climate Solutions)
2. Note: Degrees from Melbourne university were not included due to different degree structure. At the time of study USYD didn't offer Environmental Engineering. University of Queensland (UQ) was excluded as environmental engineering was not a stand-alone degree, while UQ and UWA civil engineering programs were ranked >150.

Focus study

Detailed course outlines available at UNSW were reviewed for direct or indirect mentions of sustainability, documentation included course descriptions, learning outcomes, course schedules, assessments, and resources. These were reviewed to identify situations in which there may be false negatives (instances where sustainability was not explicitly stated but implied) or false positives (courses mentioning sustainability but lacking substantial content). 'Indirect' mentions were present when included terms or concepts were judged to be related to sustainability. While this indirect approach can be considered subjective, it aims to encompass opportunities for clearer linking of sustainability concepts and identify limitations of the direct mapping approach.

Results

Inter university comparisons

The results of the benchmarking was not aiming to endorse specific approaches, but to delve into how sustainability is currently integrated in different curriculums. Core courses typically included both discipline cores, as well as some design courses or introductory courses, common for engineering students; typically run by Faculty and external to the schools.

Approaches for different universities in presenting information on handbooks, e.g. the style of writing course learning outcomes, did vary between universities, and courses. Some courses had only brief or general descriptions and CLOs, while it was much more detailed for others, potentially leading to false negatives for brief entries. When information was missing for a certain course, this was documented, and an alternate year used where appropriate. Certain subjects also stated that information was supplied elsewhere (e.g. the learning management systems) particularly for large common design subjects.

Focus study at UNSW

Mapping direct and indirect references to sustainability in both core and elective courses was conducted for the UNSW Environmental and Civil Engineering programs. A few false positives were identified, where sustainability was referenced but did not appear to be integrated in the course materials. This occurrence was observed in two elective subjects where sustainability only appeared in the course name or description, but its integration into the course content remained unclear based on the available documentation. This may either indicate a limitation in this methodology, paucity in the documentation or the possibility of the terms being used inaccurately or with a potential for greenwashing.

The focused study also unveiled four courses that indirectly referred to sustainability as being covered in the course. The common indirect reference involved evaluating designs considering social, economic, and environmental factors, the main components of the sustainability model.

Table 2: Number of courses directly referring to sustainability in core subjects for Civil and Environmental Engineering programs at selected universities.

	Civil Engineering					Environmental Engineering				
	No. of courses		% of courses with direct mentions that are also:			No. of courses		% of courses with direct mentions that are also:		
			Design	Internal	CLOs			Design	Internal	CLOs
Adelaide	4 of 24	17%	25%	50%	100%	6 of 24	26%	30%	60%	100%
Monash	3 of 21	14%	100%	33%	67%	5 of 22	30%	71%	29%	86%
UNSW*	4 of 24	17%	50%	30%	75%	7 of 25	28%	50%	50%	83%
USYD	2 of 26	8%	0%	100%	100%	-				
UWA	-					2 of 30	7%	0%	100%	50%

Design: % of core course directly mentioning sustainability that are design type courses
Internal: % of core courses directly mentioning sustainability that are administered by the School (vs External schools or Faculty)
CLOs: % of core courses directly mentioning sustainability that refer to sustainability **in their CLOs** (rather than course description)
*Recommended level 1 prescribed electives were taken as core subjects at UNSW
Research Thesis Subjects or final year projects are excluded from this analysis – foundational subjects potentially needed for fundamental pre-requisites are also excluded. Foundational maths or science subjects and their advanced options are grouped.

Table 3: Number of courses directly referring to sustainability in discipline elective subjects for Civil and Environmental Engineering programs at selected universities.

	Civil Engineering			Environmental Engineering		
	No. of courses	% of courses with direct mentions that are also:		No. of courses	% of courses with direct mentions that are also:	
		Internal	CLOs		Internal	CLOs
Adelaide	4 of 17 Up to 6 available	75%	75%	6 of 11 Up to 6 available	33%	33%
Monash	5 of 35 Up to 6 available	100%	80%	6 of 30 Up to 6 available	50%	100%
UNSW	12 of 34* Up to 3 available	83%	25%	7 of 22* Up to 2 available	86%	29%
USYD	5 of 32 Up to 5 available	100%	50%	-		
UWA	-			No discipline specific electives (all core)		

*Not all listed electives were available in years 2021 and 2022, only those running in this period were reviewed
Internal: % of courses directly mentioning sustainability that are administered by the School (vs External schools or Faculty)
CLOs: % of courses directly mentioning sustainability that refer to sustainability **in their CLOs** (rather than course description)

Figure 2: Number of courses directly mentioning sustainability A) in the course learning outcomes (CLOs), and B) for different level of core courses and style of learning (design vs content).

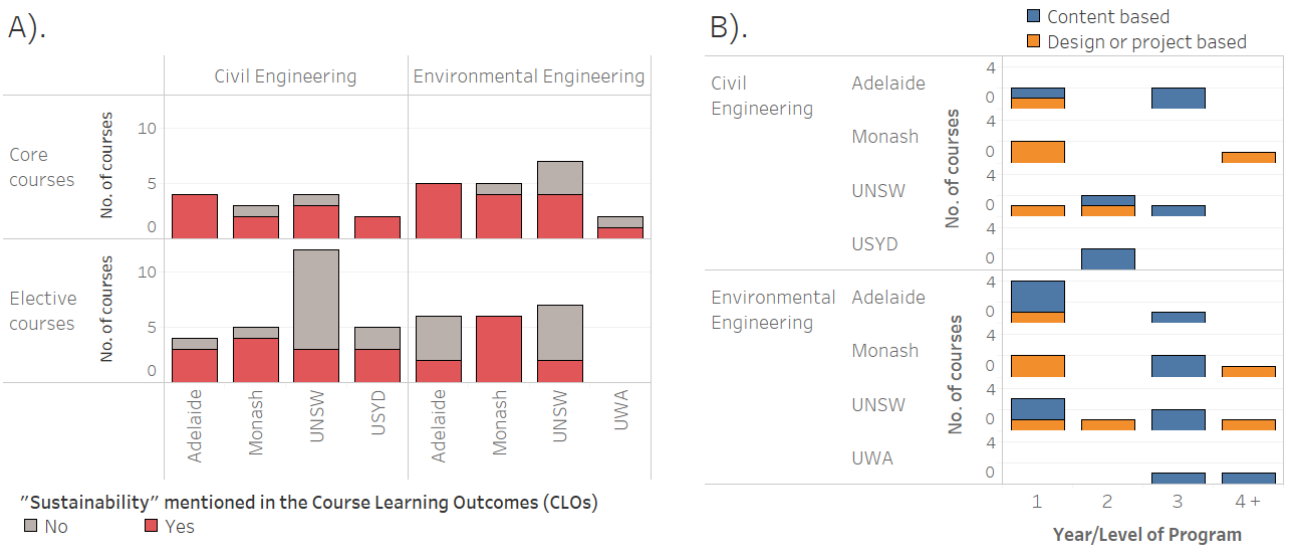

Table 4: Types of topics/themes in courses directly addressing sustainability in non-design type courses. Entries in bold were judged to be addressed in-depth throughout the course(s).

	Civil Engineering		Environmental Engineering	
	Core	Electives	Core	Electives
Adelaide	• Infrastructure (incl transport) • **Systems Engineering** • Geotechnical engineering	• Groundwater • **Circular economy** • ***Infrastructure***	• Infrastructure • **Environmental systems** • **Circular economy** • **Systems engineering**	• ***Infrastructure*** • Building design • **Energy management** • **Sustainable cities** • **Environmental management** • Groundwater
Monash	*Only design subjects*	• Transport (x3) • Resource management (mining) (x2)	• **Sustainable business** • **Building design**	• **Society/Poverty** • **Cleaner production** • Transport (2) • Resource management (mining) • **Materials**
UNSW	• Construction materials • Transport	• **Humanitarian** • Structures • Waste • **Materials** • Transport • **Industrial Ecology** • **Sustainability assessment** • **Construction** • **Infrastructure**	• **Ecology/Environmental systems** • Transport • **Environmental frameworks (x2)**	• Infrastructure • Construction/materials • Transport • Waste • Remote sensing • **Industrial Ecology**
USYD	• Transport • **Environmental frameworks**	• **Humanitarian (2)** • Transport (2) • Structures		
UWA			• **Environmental systems** • Water	*No discipline electives*

Many 'focused' sustainability subjects cover details that are somewhat overlapping, the following classifications have been used.
Environmental frameworks – description of environment and impacts associated with project planning and approvals
Environmental systems – operation of environmental systems and cycles
Systems engineering – designing and managing complex process and infrastructure systems, e.g transport.
T*hose in bold and italics were thought to be design/content type course*s

Discussion

Study effectiveness

The methodology employed in this paper, though basic, serves the purpose of indicating how sustainability is incorporated throughout degree programs, with similar approaches being used as a recent screening study (Bury et al., 2022). Nevertheless, it does possess certain limitations:

- Data availability: Not all handbooks or course outlines provided the same level of detail.
- Documentation approach: Different universities may approach documentation differently, e.g. the number of course learning outcomes, and how they are written.
- Subjective identification of indirect coverage: Identifying indirect references to sustainability in the UNSW focus study involved subjective judgment, which may introduce bias.

In contrast to solely relying on documentation, other authors, such as Daniell and Maier (2005), used course coordinator self-assessment to map dimensions of sustainability (economic, social, environmental, infrastructure) in Civil & Environmental Degree Programs at Adelaide University. While their detailed review provided valuable insights, it relied heavily on course convenors' participation and perceptions of sustainability, which occasionally led to instances where sustainability aspects were not explicitly referenced or recognized by the coordinators. In terms of methodologies, the term analysis approach used in this paper, offers the advantage of highlighting opportunities for clearer communication and better scaffolding of sustainability into programs at a higher level.

Integration → big picture thinking

Among the programs assessed, it was observed that three out of the four reviewed Environmental Engineering programs and one of the four Civil Engineering programs explicitly mentioned sustainability in their overall program descriptions (Table 1). Given the important role engineering graduates in providing robust and resilient infrastructure, as well as the interest and value assigned by students towards sustainability (Shillaber et al., 2017), this is an area that could be improved. There is therefore an opportunity, particularly for Civil Engineering programs, to indicate to prospective students how the program equips them with essential knowledge and skills in sustainability for their future roles. Notably, Environmental Engineering programs demonstrated a stronger emphasis on sustainability, aligning with their focus on understanding environmental impacts and environmental protection—an expected outcome. Indeed, these graduates are increasingly sought after for careers in sustainability assessment and management.

While the G08 universities studied deliver the same qualification, they exhibit distinct expertise through their diverse range of offered courses. This is particularly evident for the Environmental Engineering degrees. For instance, UWA employs less "sustainability or sustainable" terminology in its environmental engineering degree, focusing instead on subjects related to environmental protection, understanding natural systems, and pollution prevention. On the other hand, the Environmental Engineering degrees at Adelaide and Monash place specific emphasis on clean energy and supply chains, respectively, as reflected in their core and elective subjects. Indeed Adelaide's degree is specifically named "Bachelor of Engineering (Honours) (Environmental and Climate Solutions)," further underscoring its distinct specialization.

In all the reviewed universities both Civil and Environmental Engineering programs were run from the same School. Changes in the Environmental Engineering program focus therefore also influenced available electives for Civil Engineering majors. This was also noted for other programs administered by the same school (Surveying at UNSW or Resource Management at Monash).

Given the changing industry landscape and evolving graduate expectations, it becomes imperative to highlight graduates' responsibilities as professional engineers to ensure sustainability right from the inception of their degree. Chau (2007) reorientated a Civil Engineering degree by placing a strong focus on graduates' professional responsibilities for pollution prevention in design choices. Having a clear sustainability vision could not only attract students (Shillaber et al., 2017), but also encourage course coordinators to emphasise relevant aspects in content already being delivered – aiding the scaffolding of information and enabling students to create meaning and link concepts (Barrella & Watson, 2016). A nice example was found in two UWA courses that linked course content back to the UN Sustainable Development Goals.

Horizontal vs vertical

Curriculum structures can be categorized as vertical (individual standalone courses) or horizontal (across a variety of classes). Horizontal integration of sustainability has shown to generate broader, deeper, and more interconnected knowledge for students (Barrella & Watson, 2016). This approach offers valuable opportunities for specific real-world case studies from diverse perspectives, relevant to students' disciplines or majors. However, implementing horizontal integration poses challenges in overcrowded and underfunded engineering programs (Hall & Barger, 1998). Indeed, a common reason cited for poor sustainability integration is constrained course curricula. Nonetheless, Lu (2015) demonstrated that integrating sustainability into an introduction to environmental engineering course did not compromise the technical content. Such integration was achieved by emphasizing case studies, current issues, and involving invited professionals, while broadening design outcomes to include economic, social, environmental, and technical aspects.

Certain subjects naturally lend themselves to aligning with sustainability. For instance, Civil Engineering transport subjects often directly mention sustainability in the context of sustainable transport systems, mode choices, system design, and low carbon technologies. Most of the reviewed programs had direct sustainability mentions in transport subjects (Table 4). This mapping exercise demonstrates that the delivery of sustainability integration into Civil Engineering degrees has opportunities for improvement, the importance of which has been the focus of many researchers (Brown et al., 2015; Chau, 2007; Jowitt, 2004). There are more opportunities for integration

particularly in relation to sustainable design of buildings and infrastructure for both the reviewed Civil and Environmental Engineering programs.

While the value of horizontal integration is clear, there is still a place for standalone sustainability subjects, which can delve into different sustainability assessment approaches and avoid greenwashing or narrow views of sustainability (e.g., focusing solely on carbon reduction). As shown in Table 4, many courses that have a strong sustainability focus had topics such as Environmental Frameworks, or Industrial Ecology; however differences were noted in the types of courses in Civil and Environmental Engineering programs. Emphasising sustainability in subjects such as Environmental Management, commonly taught to both environmental and civil engineering students, can help to reinforces sustainability content throughout the curriculum (Hall & Barger, 1998). By adopting both vertical and horizontal integration strategies, universities can develop well-rounded engineering graduates who are proficient in sustainability principles, poised to address complex challenges and create a sustainable future.

Surveys conducted at other institutions found that while sustainability is of interest to students, there were opportunities to improve how sustainability was consistently introduced throughout their program, rather than only introducing it at the end (Shillaber et al., 2017) and provide more guidance in integrating sustainability in the design process (Watson et al., 2013).

By mapping over course levels (e.g. level 1 courses are typically taken in year 1) an indication of how students are exposed to sustainability content in core courses can be obtained (Figure 2B). Typically, sustainability was mentioned mostly in Level 1 courses with design or project-based course types. While Environmental Engineering programs have more core courses mentioning sustainability compared to civil engineering, they still have gaps, particularly in the second year. There are clear opportunities to increase the delivery of sustainability in higher level courses in all the reviewed Civil Engineering programs.

What is delivered - *Design vs content*

In the context of design activities, it is essential for students to understand the significance of incorporating not only environmental but also economic and social influences and constraints. As such, sustainable design is a clear requirement for any engineering design task. The review of programs revealed that design courses that used project based learning were not consistently linked with explicit sustainability outcomes across universities (Table 2, 3). Some institutions, such as Monash and UNSW, demonstrated a high number of design courses addressing sustainability, while others like USYD and UWA did not show direct links to sustainability concepts in the reviewed material.

Design-type courses offer advantages in introducing sustainability to students, as they foster debates and justifications, aligning well with the nuanced and multidisciplinary nature of sustainability. However, it is crucial to ensure that sustainability is not merely addressed superficially, such as focusing solely on a single aspect like carbon emissions, to meet design outcomes. While early-year design courses are typically administered by Faculties, emphasizing multidisciplinarity, there may be challenges when applying these concepts specifically to focused disciplines. Later courses should ideally build on this introductory knowledge and apply it to disciplinary content. Some capstone design courses appear explicitly positioned to investigate sustainability, exemplified by courses like CEME4009 "Decision Making for Sustainable Solutions" at Adelaide and CVEN4701 "Sustainable Infrastructure" at UNSW.

A case study by Price and Robinson (2015) highlighted the significance of scaffolding sustainable design principles into civil engineering courses and building on these principles throughout students' careers. Indeed a framework for integrating sustainability concepts in constrained curricula was proposed by Christ et al. (2015); it contains key elements of introducing students to sustainability motivation in initial courses, then showcases application in later ones.

In the reviewed programs, while many universities emphasize design courses, linking sustainability concepts throughout the years may be lacking, and is also complicated by differences in course ownership and transitions between schools and faculties risking overlaps or gaps in content.

Multidisciplinary and critical thinking

Cross-disciplinary thinking and skills play a pivotal role in fostering sustainability-relevant knowledge (Chau, 2007). Given the collaborative nature of the engineering profession, this broader understanding is essential for effectively managing diverse socioeconomic and environmental factors and engaging with stakeholders. Offering subjects from other schools or disciplines as core or elective courses can support more holistic sustainability definitions, especially with regard for social dimensions. For Environmental Engineering, Adelaide and Monash universities demonstrated a highly multidisciplinary core and electives lists, with many direct mentions of sustainability being administered by other schools (Table 3). This approach can help to address social sustainability areas that engineering teaching staff may not be as familiar with. On the theme of social dimensions, humanitarian engineering courses offered by several universities (USYD, UNSW) also provide a valuable means to focus on social dimensions, which are typically challenging to deliver (Daniell & Maier, 2005). While some may fear that taking courses in other schools could compromise core technical knowledge, engineers need not become experts in all domains; rather, they should feel comfortable and fluent in collaborating with experts from various fields and incorporating sustainability into their work (Davidson et al., 2007).

Conclusions and Recommendations

This paper mapped the inclusion of sustainability terms in course documentation of Civil and Environmental Engineering programs at five G08 universities in Australia. Results showed the importance of design courses in introducing sustainability to students, particularly for first year courses. Sustainability was typically more commonly incorporated into Environmental Engineering degrees, however topics such as sustainable transport were common in most reviewed programs. Many courses mentioning sustainability were administered externally (by faculty or other schools), potentially leading to overlaps or gaps in content, but with the advantage in exposing students to other disciplines. Cross-disciplinary study can produce well-rounded graduates equipped to tackle complex sustainability challenges. In light of the findings from this study, we propose the following recommendations.

Clearly establish the sustainability vision in programs: Universities should establish the overarching sustainability view for educational programs and emphasise the responsibilities of professional engineers to effectively practice sustainable design. This is nicely summarised by Jowitt (2004) to “make a difference at the heart of the learning process rather than tinker at the fringes of the curriculum”.

Being clear with terminology and linking with themes: From the focused study at UNSW, without specifically mentioning in the course outlines or readily available materials, many courses did in some way address sustainability. Linking concepts or examples back to the overarching sustainability vision of the program and using consistent terminology would help students to better appreciate and apply sustainability principles.

Overall, this paper emphasizes the importance of reviewing and updating engineering curricula to better incorporate sustainability principles.

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