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Article

Managing Knowledge to Promote Sustainability in Australian Transport Infrastructure Projects

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Abstract: To deliver tangible sustainability outcomes, the infrastructure sector of the construction industry needs to build capacities for the creation, application and management of ever increasing knowledge. This paper intends to establish the importance and key issues of promoting sustainability through knowledge management (KM). It presents a new conceptual framework for managing sustainability knowledge to raise the awareness and direct future research in the field of transport infrastructure, one of the fast growing sectors in Australia. A holistic KM approach is adopted in this research to consider the potential to "deliver the right information to the right person at the right time" in the context of sustainable development of infrastructure. A questionnaire survey among practitioners across the nation confirmed the necessity and identified priority issues of managing knowledge for sustainability. During infrastructure development, KM can help build much needed industry consensus, develop capacity, communicate decisions, and promote specific measures for the pursuit of sustainability. Six essential elements of the KM approach and their priority issues informed the establishment of a conceptual KM framework. The transport infrastructure sector has come to realise that development must not come at the expense of environmental and social objectives. In practice however, it is facing extensive challenges to deliver what has been promised in the sustainability agenda.

This research demonstrates the importance of managing sustainability knowledge, integration of various stakeholders, facilitation of plans and actions and delivery of tangible benefits in real projects, as a positive step towards meeting these challenges.

Keywords: infrastructure; transport projects; sustainability; knowledge management; practitioner perceptions

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1. Introduction

Infrastructure in the Australian context typically includes utilities such as roads, ports, railways, power lines, water pipes, power generation buildings, sewer plants, and other tangible structures [1]. Transport infrastructure systems, consisting of highways, roads, railways and ancillary facilities such as bridges, are often considered as the backbone of a country's economy. They support basic urban activity and play a fundamental role in determining the nation's economic efficiency and productivity [2,3]. Over the recent years, the growth of Australia's dispersed population in emerging regional centres, the boom of resource exports, growing social expectations, and international competition have been the driving forces of infrastructure development and regeneration [4–6]. Most projects are in the transport segment, including road networks, railway links and airport expansions.

While responding to the growth with real action plans, local, state and federal governments have recognised that infrastructure development can cause significant economic, environmental and social concerns [7,8], which are the foundational pillars of the commonly recognised triple bottom lines (TBL) of sustainability. Infrastructure development, particularly transport-oriented, is closely related to all facets of sustainability, as it often requires significant levels of resources and finance, causes disturbance to the natural environment and impacts upon the local community [9]. With depleting resources, increasing public awareness on wellbeing, stronger evidence of climate change and the global economic slowdown, it is not difficult to build a logical link between sustainability and transport infrastructure. On the positive side, expanding and regenerating Australia's infrastructure system has been seen as the principal means of enhancing economic growth and national productivity [3,8,9].

Increasingly, stakeholders accept that the development of infrastructure must not come at the expense of the environment and social objectives. As an example, in Queensland, the Department of State Development, Infrastructure and Planning replaced the Integrated Planning Act with the Sustainable Planning Act 2009 [10], to reflect a stronger focus on ecological sustainability as the outcome of planning decisions. Within only a few years, the Act was changed to the Sustainable Planning (Infrastructure Charges) and Other Legislation Amendment Act 2014, to embrace new requirements [11].

Practitioners of the infrastructure sector generally agree that infrastructure sustainability can be delivered through incorporating sustainable solutions into design, construction and operation of the transport facility. In practice however, they are facing extensive challenges to apply sustainability principles into their professional domains and real projects to deliver tangible outcomes [2,12]. According to past research, the challenges may be manifold. Immaturity and uncertainty of the body of ever increasing sustainability knowledge, different interpretation of starting and ending points, varying professional perspectives and priorities, the lack of exemplar projects, and shortage of knowledgeable practitioners are just a few examples [13–16]. Compared to other fields such as buildings, sustainability in infrastructure development has not received as much research focus as it requires [15,17].

Pathriage *et al.* [18] argue that the construction industry needs to intensify its efforts to move to a knowledge intensive mode. It is also believed that better decision-making towards sustainability goals can only be achieved when stakeholders are informed of and continuously updated with new concepts, knowledge and expertise across organisational, professional and hierarchical boundaries [19]. Furthermore, as stated by Wallace [20], sustainability needs multi-disciplinary collaboration and innovative solutions, which are highly dependent on a knowledgeable workforce, good communication and a culture of care and innovation. There is a clear and urgent message to the infrastructure sector to not only build and expand the body of sustainability knowledge among practitioners, but also find a better way to manage it at individual, project, organization and industry sector levels.

From a functional perspective, knowledge management (KM) can be seen as a "systematic approach to manage the use of information in order to provide a continuous flow of right knowledge to the right people at the right time, enabling efficient and effective decision making in their everyday business" [21]. Despite being a relatively new concept, KM is regarded as a broad and expanding tool to manage new information in diverse contexts in industries and businesses [22,23]. KM has shown its worth through existing applications in the building construction sector [24–26]. Various attempts have been made to develop strategies and mechanisms to manage construction knowledge [24,27]. However as shown by earlier examples, few have incorporated sustainability issues and requirements in infrastructure works [18,28–31].

With reference to literature and findings of related work in other construction sectors, this paper discusses results of a recent questionnaire survey among transport infrastructure practitioners which helped verify the necessity, determined priority issues and outlined focus areas for managing sustainability knowledge. They responded to six aspects of KM issues from individual professional experiences as well as project and organizational circumstances. Stemming from this finding, a conceptual framework of managing sustainability knowledge is developed for practitioners to promote a holistic KM approach to facilitate sustainability knowledge creation, capture, share and application in the Australian transport infrastructure sector. It will also be used as the foundation for on-going research work on the processes and guidelines of knowledge management specific to this industry sector.

2. Research Method and Data Collection

2.1. Research Focus

Knowledge needs to be managed for effective applications. Knowledge management is an expanding topic contributed by a diverse range of disciplines such as cognitive science, information technology, organisational theory, library and information sciences, and document and information management, with a multi-fold mix of strategies, tools, and techniques [22,23,32]. In this research context, sustainability knowledge can be defined as the type of knowledge that improves the understanding, uptake, and end results of sustainability during projects' life cycles. For transport infrastructure development, sustainability knowledge may come in the form of past experiences, design ideas, guidelines and policies, rating tools and indicators and technology innovations (Table 1).

Table 1. Types, locations and characteristics of sustainability knowledge examples.

-	Project Experiences	Government Guidelines/Polices	Assessment Tools/Indicators	Underpinning Theory/Technology
Location	Individuals	External resources	External resources	External
Type	Explicit/tacit	Explicit	Explicit	Explicit
Characteristic	- Mostly reside in people minds; - Hard to track, record and widely share.	- Vague and general. - More about environment protection	- Mainly developed from building assessment tools - More for environment performance assessment - Evolving in nature	- Complex and should consider extra systems - Many of them do simply not exist currently

Embedding sustainability principles for project delivery presents many challenges [17]. Wallace [20] summarised five important conditions to be met in order to improve project sustainability performance: (1) a knowledgeable and committed project owner; (2) a high-performance project team; (3) alternative procurement and contracting mechanisms; (4) high but achievable sustainability goals and objectives; and (5) access to and willingness to share knowledge and achievements. With reference to previous studies on managing knowledge in the construction industry, the authors considered how transport infrastructure development processes relate to these conditions and decided on a survey study focusing on six key KM elements as listed below:

- The body of sustainability knowledge
- KM strategy
- Stakeholder integration
- KM process
- KM enablers
- Outcomes of managing sustainability knowledge

2.2. Survey Distribution

A structured questionnaire, consisting of nine sections with 37 questions, was developed to collect practitioners' opinions on the abovementioned key elements. Research objectives, methods and approach, and literature review findings guided the formulation of the survey questions. As the majority of the survey questions are concerned with the prioritisation of perspectives rather than dealing with relationships among factors, they were framed on a five-point Likert scale with the mean, frequency and standard deviation of the grouped data assessed to determine the rank order. Because of this, the analysis used simple statistics to consider Means and Standard Deviations only, rather than engaging non-parametric studies.

Respondents were selected from the main stakeholder categories involved in large transport infrastructure projects in Australia, representing both public and private sectors, e.g., general contractors, subcontractors, suppliers, government agencies, consulting firms, and clients.

The survey was conducted through an online survey tool named Survey Monkey, which helps publish surveys on a website and generate pass code and filters to collect responses.

The first distribution approach was through email. Initially, 120 potential respondents were selected from leading organisations that worked on transport development projects across Australia, using a combination of existing industry databases, online search, and recommendations from industry-based research collaborators. They were each given a login name and password to the online survey by email. The initial responses were monitored. Non-respondents were followed up during the course of the survey with email reminders. In the end, out of the 120 questionnaires mailed to the potential respondents, 18 invitations were returned undelivered and 39 received responses. A total of 31 out of the 39 responses were fully completed and considered valid for data analysis, which gives an effective response rate of 30% (31/102) in this first part.

The second distribution approach was via professional associations. AIPM (Australian Institute of Project Management) and Engineers Australia (EA) offered their assistance by including the survey information in their regular newsletters. A specific online collector was set up to collect these responses. Twenty-eight were collected during the course of the survey, out of which 18 were valid for full completion of the survey as well as fitting the required respondent profile. However, it was not possible for the researchers to identify how many potential respondents were reached through this method, and potentially, only a small percentage of AIPM and EA members may have fulfilled the requirements of this survey.

In the end, 49 valid responses were used for data analysis. This study considers the prevailing opinions and common practices of managing knowledge in order to identify priorities and portray a general picture, as the foundation for further research.

2.3. Survey Respondents

Figures 1–3 shows the characteristics of the respondents. Figure 1 shows that about 70% of the respondents have more than 10 years of professional experience. Figure 2 shows that 86% of them are from engineering and project management professional backgrounds directly required and involved in infrastructure projects. This confirms the suitability and authenticity of the data collected. This also made the researchers decide not to use non-parametric analysis to consider group dynamics.

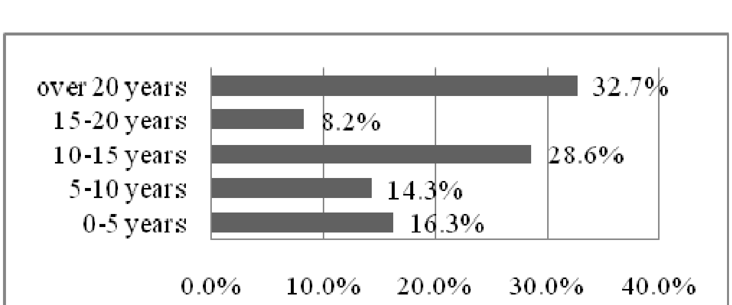

Figure 1. Respondents' professional experience in the infrastructure sector.

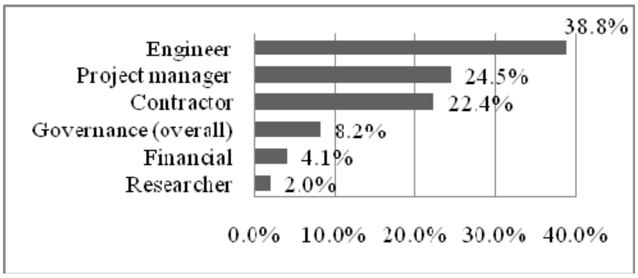

Figure 2. Professional role of respondents.

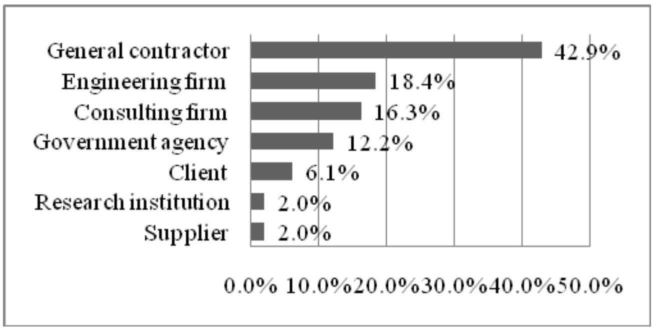

Figure 3. Organisation's type.

Respondents are from both public and private organisations, and together represent every stakeholder type in the industry (Figure 3). The main portion of the respondents is from the general contractor (42.9%), which is the main stakeholder in the transport infrastructure sector. Others are from engineering firms, consulting firms and government agencies (18.4%, 16.3% and 12.2%, respectively). The category of organisation is based on self-description by the respondents, thus there might be a slight overlap between engineering firms and consulting firms as some of the consulting firms provide specialised engineering services. Only 2% represented clients of infrastructure projects. Part of the reason is that it is hard to recognise or target clients of infrastructure markets. The other is because many infrastructures are state owned or temporally owned by the private sector (e.g., BOT/PPP projects), thus some of the real clients are hidden in the contractor and government agency category.

3. Research Findings

The authors analysed valid questionnaires using simple statistics to portray a general picture of KM application in the transport infrastructure sector. Findings are categorised into the six key KM elements described in the last section. Accordingly they are discussed in the following six sections.

3.1. KM Strategy

Knowledge management encompasses a systematic approach to managing the use of information. In this way, it provides a continuous flow of knowledge to enable the efficient and effective decision making by key decision makers. The approach is underpinned by a KM strategy, which enables an aim and focus for KM activities [22].

According to the results in Table 2, the logical link and necessity of adopting KM to promote sustainablity application in infrastructure developement has again been confirmed. It is widely accepted that sustainability considerations are very important (4.47/0.58) and managing related knowledge are considered greatly helpful (4.22/0.65). Respondents also believe that achievements in sustainability contribute to organisational performance.

Table 2. Linkage between infrastructure, sustainability and KM.

Statements	Mean	SD
Sustainability issues need to be considered when developing infrastructure projects.	4.47	0.58
Consideration of sustainability issues can help my organisation's performance.	4.08	0.95
Managing related knowledge will help in promoting the sustainability of infrastructure projects.	4.22	0.65
My organisation currently has a KM strategy or is willing to have a KM strategy.	3.47	0.92
In my organisation, there are specific KM criteria to manage sustainability knowledge.	3.14	0.89

Note: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Srongly Agree.

With strong competition over the volatile economic conditions in the last decade, some construction organisations have begun using KM to obtain and maintain advantages [33]. However, according to this survey, most of the infrastructure practitioners hold reservations on the current usage of KM according to their experience. In their opinion, KM is still a new concept. For the infrastructure sector, there is no general KM process or framework to follow.

Table 3 shows the main impetus ranked by the respondents in promoting sustainability pursuit and application in the organisation. The biggest drivers in this regard are client awareness and requirement, business benefit, government regulation/legislation and social responsibility.

Table 3. Main Impetus for promoting sustainability pursuit and applications.

Rank	Impetus	Mean	SD
1	Client's awareness and requirement	4.45	0.77
2	Business benefits	4.10	0.87
3	Government regulations and legislation	4.04	0.96
4	Organisational reputation	3.88	0.88
5	Social responsibility	3.63	1.23
6	Community awareness	3.50	0.96
7	Improved competitiveness through labels, such as "Green Firm"	3.39	1.24
8	Threat of climate change and/or other global crisis	3.33	1.30
9	Problem solving	3.24	1.22
10	Use of new procurement method in which the developer is responsible for maintaining the project for a period (e.g., PPP, BOT)	3.10	1.25

Note: Level of Importance: 1 Low → 5 High.

Client awareness and requirement are the most important impetuses (highest mean, lowest standard deviation), something which is also frequently suggested by the literature. In real projects, if the client is not particularly interested in sustainability, the contractor usually is unlikely to actively pursue it, as the contracting industry will typically do just enough to get the project built and pushes the community or social issues back to the client. It is common that the whole development is driven by client's documentation. To truly progress sustainability, clients need to be adamant in the project proposal and be clear about the requirements.

The main barriers to the application of sustainability knowledge are listed in Table 4.

Table 4. Key Barriers to pursue and manage sustainability knowledge.

Rank	Barrie	Mean	SD
1	Difficult to measure the return on investment	4.04	1.02
2	Lack of co-ordination and consensus between stakeholders	3.73	0.95
3	Sustainability concepts are not well understood	3.73	1.00
4	Hard to connect sustainability target with organisational business strategy	3.61	0.81
5	Highly fragmentary nature of the industry	3.55	1.04
6	Will increase project budget/cost	3.47	1.26
7	No standardisation of key processes to follow	3.43	1.15
8	Project-oriented nature of the business development type	3.35	1.28
9	Labour-incentive nature of the infrastructure construction industry	3.16	1.39
10	Lack of top management's commitment	3.12	1.03
11	Complex nature of infrastructure project development	2.98	1.15
12	Poor financial resources	2.90	1.19
13	Poor non-financial resources	2.82	0.97
14	Long duration of infrastructure project development	2.74	1.22
15	Will extend project completion period	2.73	1.22
16	Will generate higher risk	2.67	1.39
17	High staff turnover	2.56	1.15
18	Intellectual Property protection issues	2.51	1.24

Note: Level of influence: 1 Low → 5 High.

"Business benefits" is ranked second in Table 3. This shows that sustainability will be strongly promoted if organisations can see tangible results from its application. However, as shown in Table 4, the biggest barrier is the difficulty in measuring investment returns in regards to sustainability (4.02/1.02). As sustainability applications in transport infrastructure are still being explored, industry best practices and exemplar projects are rare. The body of knowledge provides limited underpinning for the industry to tangibly measure the input and output of sustainability. Easy-to-follow frameworks and examples should be put on top of the development agenda.

The limited understanding of the sustainability concept and the lack of consensus between stakeholders are the second big hurdles which may strongly limit people's absorptive ability and differentiating ability towards more sustainable designs and activities. Literature suggested that the lack of general and professional education is one of the reasons [17,34]. Better decisions can only be made if all the stakeholders have abundant and up-to-date knowledge to tap into. It also makes a big difference if they deeply care about sustainability through internal volition. For example, it is common in the construction industry that people see sustainability as another expression of "environmental protection". Such views narrow the scope of professional responsibility, as well as the opportunities to perform beyond compliance.

3.2. The Body of Sustainability Knowledge

Table 5 describes the current quality of the body of sustainability knowledge. Respondents agree that sustainability knowledge is very subjective (4.12/0.63) and challenging to acquire (3.73/0.95). As suggested by the literature, sustainability can only be achieved though a multi-disciplinary approach, which is especially important for infrastructure development, as the knowledge is fragmentary and evolving constantly [20,33].

Table 5. Characteristics of sustainability knowledge for infrastructure development.

Rank	Statement	Mean	SD
1	It is subjective, means different things to different people.	4.12	0.63
2	It is challenging to acquire.	3.73	0.95
3	It is dynamic and evolving constantly.	3.61	0.95
4	It is fragmentary.	3.59	0.86
5	It is challenging to articulate and comprehend.	3.59	0.81
6	It is embedded in personal mind, hard to be codified and transferred.	3.33	0.88
7	It is challenging to be adjusted and used in other project.	3.22	0.94
8	It is immature to be implemented.	3.14	0.91
9	It is contextually/culturally sensitive.	2.94	0.94

Note: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Srongly Agree.

Table 6 lists the main sources through which industry practitioners can obtain sustainability knowledge. People tend to find help within the organisation as colleagues and internal experts are ranked the highest (4.2/0.84, 3.92/0.84, respectively).

Table 6. Primary sources for sustainability knowledge.

Rank	Knowledge Resource	Mean	SD
1	Colleagues	4.2	0.84
2	Internal expert	3.92	0.82
3	Industry best practice	3.59	1.10
4	Deliverables from previous stages	3.49	0.84
5	External consultant	3.31	1.16
6	The construction project team	3.31	0.99
7	Internal training/workshop/seminar	3.29	1.08
8	Government agency	3.00	1.10
9	Quality Assurance Process	2.90	1.14
10	Research institution	2.86	0.96
11	Internal database	2.90	1.03
12	Industry association	2.73	1.25
13	Other industry	2.55	1.08
14	Other organisation	2.45	1.26
15	Local communities	2.49	1.06

Note: Level of Importance: 1 Low → 5 High.

It is common nowadays for organisations to use internal databases for information storage and applications. Many also invest heavily in computer tools that can generate various reports. However, respondents of this survey do not currently see internal databases as a highly valued knowledge resource. Reasons for this can vary. While specialised computer packages are important, better-structured catalogue systems and more user-friendly and controllable databases can be just as helpful. Furthermore, an index of expert and knowledge maps can be an efficient and applicable tool for locating sustainability knowledge.

Sustainability knowledge is people- and projects-based. Thus a “subject” KM approach should be developed which puts emphasis on ways to promote, motivate, encourage, nurture or guide the process of knowing, and abolishes the idea of trying to capture, then distribute knowledge. This view mainly understands KM as a social communication process, which can be improved by collaboration and cooperation support tools. In this approach, knowledge is closely tied to the person who developed it and is shared mainly through person-to-person contacts. The main role of Information and Communication Technology (ICT) in this case is to help people to communicate knowledge, not store it.

The authors also attempted to categorise sustainability knowledge according to respondents, however taxonomy could not be built by using the survey results. The top three ranked items are lessons learned from internal projects (4.24/0.85), staff personal capabilities/skills/experience (4.06/1.05) and industry best practice (4.00/0.89). This finding echoes the observation that the main carriers of sustainability knowledge are exemplar projects, as well as experienced and knowledgeable industry professionals.

3.3. Infrastructure Stakeholder Integration

Construction professionals, from both private and public sectors, are under pressure to maximise economically feasible, socially viable and environmentally accountable project outcomes. They will require the adoption of sustainability principles during project conception, design and planning, and innovative technologies and products during construction and operation. However, due to their different level of input and their professional influence, the implementation of sustainability in a certain project always highly relies on the stances of the key stakeholders and their priorities.

Table 7 lists the ranking of the influence of the main stakeholders in regard to the pursuit and management of sustainability knowledge, while Table 8 shows the current status of willingness of different stakeholders regarding the same.

The client is considered the most powerful stakeholder (4.49/0.82). This is consistent to findings in Table 5 that client’s requirement is the most important driver for sustainability. Project sustainability needs to be driven from the very beginning, from the project conception and proposal stage. It also needs to involve the end-user early. Designers are the key people to embed sustainability concepts and principles into the project design while the project manager is the key person to transfer the design into the actual project by managing resources, time and providing funding. As the main stakeholders for the project, clients and designers together may source sustainability consultants for extra support. The consultant is ranked as comparatively the most enthusiastic stakeholder in sustainability knowledge pursuit and application. This is their core competitive advantage. However, the attendance and influence of the consultant in a project still depends on the endorsement of the key stakeholders, especially the client.

Table 7. Influence of main stakeholders to pursue and manage sustainability knowledge.

Rank	Stakeholder	Mean	SD
1	Client	4.49	0.82
2	Designer	4.02	0.72
3	Project manager	3.67	0.99
4	Consultant	3.57	0.76
5	Government agency	3.53	1.12
6	Engineer	3.49	1.02
7	Contractor	3.12	1.07
8	Local community	2.73	1.2
9	Research institution	2.27	0.97
10	Sub-contractor	2.18	0.95
11	Quantity surveyor	2.12	0.99

Note: Level of influence: 1 Low → 5 High.

Table 8. Willingness of main stakeholders to pursue and manage sustainability knowledge.

Rank	Stakeholder	Mean	SD
1	Consultant	3.65	0.67
2	Designer	3.59	0.76
3	Project Manager	3.43	0.68
4	Client	3.41	0.91
5	Engineer	3.41	0.64
6	Government Agency	3.31	0.89
7	Research Institution	3.29	0.96
8	Contractor	3.16	0.80
9	Local Community	3.08	1.00
10	Quantity Surveyor	2.37	0.88
11	Sub-contractor	2.20	0.84

Note: Level of influence: 1 Low → 5 High.

3.4. KM for Infrastructure Sustainability

Table 9 shows the main stages of managing sustainability knowledge in a typical KM cycle while Table 10 indicates the relative difficulties of these KM tasks. Knowledge application is seen as the most important (4.65/0.60) while also being the most challenging task ranked by the respondents (3.86/1.00). To promote infrastructure sustainability and deliver tangible results, knowledge application at the project level is the critical stage, which 'links talks to actions' while other stages may happen at the organisational level.

It is interesting to see that knowledge creation is seen as the second most challenging task (3.54/1.11), however as the lowest in regards to its importance to the respondents (3.55/0.94). According to the findings of a 2002 survey by the Australian Construction Industry Forum (ACIF), the Australian building and construction industry in general is a very slow innovator, lagging behind many other sectors [35]. Today, the industry still has not changed much, as most of the respondents did not recognise the importance of knowledge creation, or at least as not high on the agenda. From the survey, a brief KM cycle for sustainability knowledge management can be proposed, which integrates "identify knowledge, obtain knowledge, share knowledge, maintain knowledge and apply knowledge", while knowledge application in the actual projects should be especially emphasised. Researchers and practitioners around the globe also consider knowledge *using* ("application", "execution", "processing", "utilisation" were used by different authors as well) as the most essential activity within KM.

Table 9. Main KM process for infrastructure sustainability.

Rank	KM Stage	Mean	SD
1	Apply knowledge	4.65	0.60
2	Share knowledge	4.39	0.79
3	Maintain knowledge	4.00	0.71
4	Obtain knowledge	3.92	0.98
5	Identify knowledge	3.86	0.96
6	Contextualise knowledge	3.65	1.20
7	Measure knowledge	3.57	0.98
8	Search knowledge	3.57	1.04
9	Store knowledge	3.55	1.06
10	Create knowledge	3.55	0.94

Note: Level of Importance: 1 Low → 5 High.

Table 10. Challenging KM tasks.

Rank	KM Stage	Mean	SD
1	Apply knowledge	3.86	1.00
2	Create knowledge	3.54	1.11
3	Measure knowledge	3.51	0.96
4	Contextualise knowledge	3.41	1.22
5	Share knowledge	3.37	0.81
6	Maintain knowledge	3.22	0.87
7	Identify knowledge	3.19	1.08
8	Obtain knowledge	3.08	0.96
9	Search knowledge	2.71	1.08
10	Store knowledge	2.63	1.05

Note: Level of Difficulty: 1 Low → 5 High.

3.5. KM Enablers

Many factors may affect the success of KM initiatives within a project team or organization, by presenting a positive environment for knowledge management. Enablers for sustainability knowledge management were investigated and are shown in Table 11 in the order of importance.

Out of the 43 listed enablers, 35 are scored over 3.5 and 13 over 4.0 on the Likert scale. Leadership, communication skill and organisation culture are the top three enablers for sustainability knowledge management.

Due to limited space, individual enablers will not be specifically discussed here. However the survey results depict that "soft" enablers are much valued than the "hard" facilities. Managing sustainability knowledge should be driven by forming leadership, establishing supportive culture and promoting personal capability, rather than focusing on IT technology and systems.

Table 11. Main KM enablers (Level of Importance: 1 Low → 5 High).

Rank	KM Enabler	Mean	SD
1	Leadership	4.71	0.50
2	Communication skill	4.43	0.58
3	Organisational culture	4.41	0.76
4	Project target	4.22	0.55
5	Team work	4.16	0.80
6	Organisational mission, vision and strategy	4.13	0.82
7	Technical expertise	4.12	0.67
8	Training and education	4.08	0.67
9	Multi-discipline integration	4.04	0.99
10	Sense of social responsibility	4.04	0.96
11	T-shape skill (having knowledge and skills that are both deep and broad; multi-disciplinary)	4.04	0.84
12	Capability to codify thoughts, conceptions and experiences *etc*. into written document	4.00	0.58
13	Stakeholder integration	4.00	0.87
14	Financial support	3.98	0.88
15	Sense of social responsibility	3.98	0.97
16	Project budget	3.90	1.01
17	Creativity	3.88	0.88
18	Innovation capability	3.88	0.78
19	Trust	3.82	0.91
20	Trust between colleagues	3.78	0.85
21	Networks of subject matter expertise	3.78	0.80
22	Financial support	3.73	0.86
23	Project risk management	3.71	0.87
24	Government administration	3.71	1.35
25	Professional education	3.69	0.82
26	Research and design	3.67	0.90
27	Change management	3.67	0.83
28	Process and organisational structure	3.67	0.69
29	Time frame	3.55	0.96
30	Industry Codes of Conduct	3.55	0.91
31	Collaboration of academics and industry practice	3.49	0.79
32	Professional association action	3.35	1.18
33	Team structure	3.31	0.85
34	Document management	3.17	0.84
35	Time management	3.16	0.75
36	Administrative support	3.14	0.96
37	IT technology and infrastructure	3.14	0.91
38	Staff incentive schemes	3.04	0.96
39	Technology and IT support	3.00	0.84
40	Increasing average profit rate	2.94	1.23
41	Ambition	2.86	1.35
42	Human resource turnover	2.86	1.04
43	Loyalty to the organisation	2.69	1.12

The listed enablers can be divided into four categories: external environment, organisational environment, project environment and personal capability. In order to make the infrastructure sector more knowledgeable and active in pursuit of sustainability, organisations should establish appropriate culture, integrate sustainability to their organisational mission and strategy and provide relevant training. Furthermore, in the project team, leadership formulation, target setting and multidiscipline and stakeholders integrations are indispensible. Industry practitioners should demonstrate communication skills and improve technical expertise while developing cooperation with other disciplines and arousing a sense of social responsibility. The industry as a whole should improve its innovation ability and promote the liaison between relevant experts.

3.6. Outcomes of Managing Sustainability Knowledge

As the infrastructure sector is highly project-oriented, outcomes are divided into two parts in this study: intermediate outcome, which is mainly achievable at the project level, and organisation's performance. Multi-choices questions were used to identify what outcomes could be improved by managing sustainability knowledge. As shown in Table 12, project reputation is the top ranked project outcome (75.3%) in this regard. It is followed by employee's sense of responsibility, value delivery, organisation's ability to exploit market opportunity and customer satisfaction, which were chosen by more than half of the respondents. The top selected area in organisational performance is corporate reputation (83.3%) while customer recognition, intellectual assets and profit come next.

Many businesses have public relations departments dedicated to managing their reputation. The findings in this study explained why some leading construction contractors publish a regular Sustainability Report as part of the marketing scheme, as well as for consultancy purposes.

Although the direct link between promoting sustainability and profit has not been clearly built, half of the respondents believe profit levels can be increased through better usage of sustainability knowledge.

Table 12. Outcomes of managing sustainability knowledge.

Rank	Intermediate Outcomes	%	Performance	%
1	Project's reputation	73.5%	Corporate reputation	83.3%
2	Employee's sense of social responsibility	69.4%	Customer recognition	68.8%
3	Value delivery	65.3%	Intellectual asset	60.4%
4	Organisation's ability to exploit market opportunity	59.2%	Profit	50.0%
5	Customer satisfaction	53.1%	Market share	47.9%
6	Knowledge leadership	46.9%		
7	Organisational adaptability	42.9%		
8	Organisational creativity	40.8%		
9	Reusable content created	36.7%		

4. A Conceptual KM Framework

The survey results brought out a number of important issues with regards to managing sustainability knowledge in the infrastructure sector. The key messages are highlighted as follows.

- Internal enablers are more important that external enablers, especially at the project level.
- Enablers are mainly soft in nature. IT tools are not considered very important.
- The first important driver of sustainability knowledge pursuit and application is the Awareness and Requirement of clients, who traditionally do not actively pursue sustainability knowledge.
- The monitoring process for sustainability application should be entwined with project management processes throughout the project and should involve the client.
- Sustainability knowledge is highly people centred. Indexing expert and best practice index can be applicable. A "subjective" KM approach should be adopted which focuses on communication and networking among industry practitioners and subject-matter experts.
- Promoting industry best practice should be at the top of the action plan for the transport sector.
- Sustainability knowledge application is the most important phase of the whole KM cycle; however, it is also the most challenging.
- The role of knowledge creation warrants more study as the respondents ranked the importance of knowledge creation the lowest, despite they believe it is highly challenging.
- According to the characteristics of sustainability knowledge, seeking consensus among stakeholders is a first priority task.
- It is not often possible to increase profit through managing knowledge for sustainability, as project sustainability itself is not often directly linked to profits. However, other important aspects of organizational performance can be improved to realize profit gains indirectly.
- Governments can impact on the KM of transport projects in the following ways:
    - Enable KM through administering the transport infrastructure sector;
    - Be a knowledge provider;
    - Promote sustainability considerations through regulations and legislation;
    - Be the most influential stakeholder and the most important driver of sustainability applications (as the client of the infrastructure projects).

The above analyses provide important clues as to how to formulate strategies on managing knowledge in the transport industry sector. Accordingly, a preliminary conceptual KM framework is proposed and shown in Figure 4.

The conceptual KM framework is organised by input, processes, and outcomes. With a focus on KM processes, it highlights the "what-to-do" aspects of an integrated knowledge management approach. Combining findings of this study and previously developed KM theories, a new KM process is proposed with recommendations on five key aspects of managing Sustainable Knowledge (SK): identify, obtain, share, apply and maintain. The framework recommends the use of specific KM strategies to facilitate KM activities such as communication of knowledgeable practitioners, recordkeeping, use and transfer of good industry practices, and stakeholder integration.

Future research will focus on "how-to-do-it" aspects according to the framework, for its potential application in construction organisations and actual infrastructure projects. The next stage of work will focus on the establishment of recommendations and action guidance for transport infrastructure practitioners. To reach this goal, interviews and case studies are considered the most appropriate mechanism. They are being carried out to elicit information.

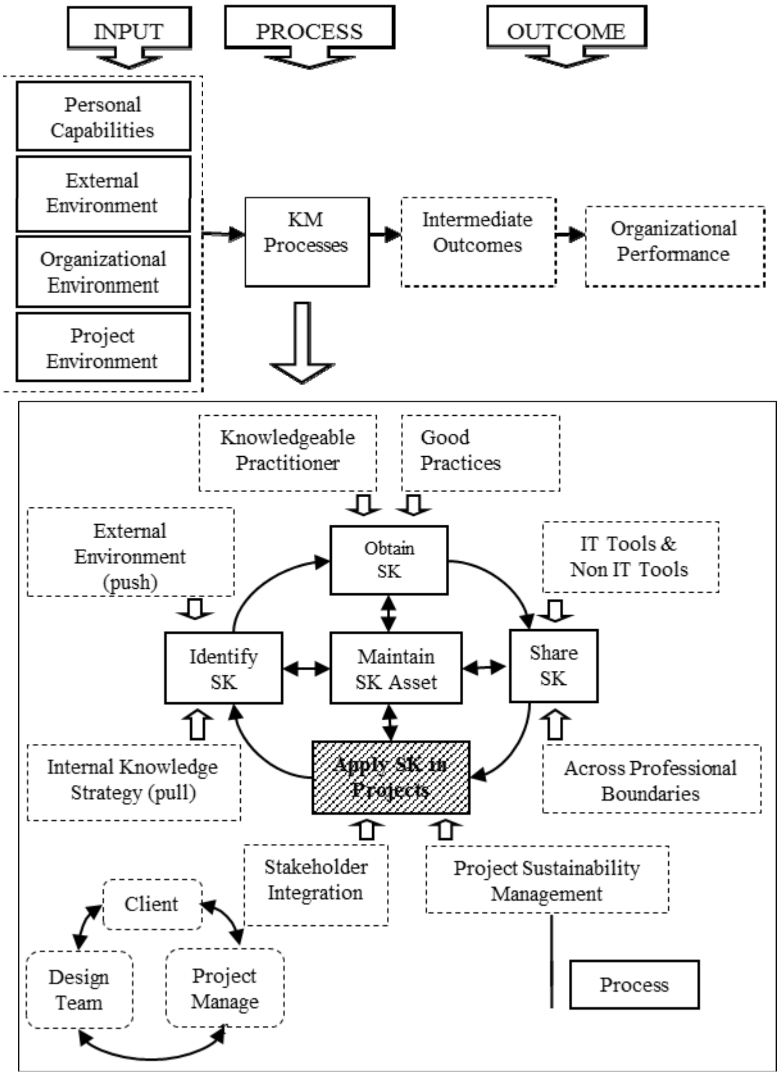

Figure 4. A conceptual KM framework.

5. Conclusions

The transport infrastructure sector is characterised by its highly project-oriented nature, a relatively conservative culture, long and arduous development processes, enormous financial undertakings, and significant potential impact on the natural environment. Therefore, it is imperative for infrastructure development to respond to the sustainability challenge. While few would argue against such principles, the perspectives, priorities and indeed the actual approaches adopted by the practitioners can largely vary, thus putting project end sustainability deliverables at risk.

Knowledge management (KM) has been proven as a useful tool to promote innovation and change in many industry sectors including building construction. However, very limited studies have been done on transport infrastructure sustainability from a KM perspective. No existing KM framework provides a holistic approach to address sustainability issues in transport projects. Through a comprehensive questionnaire survey, this research explored how sustainability knowledge is currently considered in the Australian infrastructure sector and identified the main challenges for its management. The holistic conceptual KM framework proposed here outlines the important aspects and possible strategies of managing knowledge to promote sustainability.

Interviews with practitioners and case studies are now underway to explore appropriate KM enablers, their inherent relationships and implementation strategies. This will lead to the specific procedures and guidelines of KM practice suited for this sector. By investigating the various forms of sustainability knowledge, illustrating main knowledge activities and priority requirements, and suggesting effective strategies for managing sustainability knowledge, research such as this contributes to new dimensions of disciplinary knowledge and promotes infrastructure sustainability outcomes.

Within a relatively short timeframe, this research confines itself to the issues affecting the management of sustainability knowledge at the macro level of transport infrastructure projects. Future research should consider the unique characteristics of each type of transport project, as the adopted approaches in highway projects may be different to those in bridge construction. Detailed relationships between key issues may also be examined in future. For example, contrary to the notion that innovation is critical for the success of sustainable development [36,37], this survey found that interviewees, as transport infrastructure practitioners, see creating knowledge as the least important but the second most challenging KM activity. There may be specific reasons behind this that warrant further investigation.

Author Contributions

The research reported in this paper was conducted by Mei Yuan and Jay Yang. Tan Yigitcanlar, Peter Newman, and Frank Schultmann contributed to knowledge management, infrastructure sustainability and decision making aspects of this paper respectively. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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