UNLOCKING GREEN KNOWLEDGE TRANSFER: CELL BIOLOGY INSIGHTS FOR SUSTAINABLE EXCHANGE IN ENGINEERING PROJECTS

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ABSTRACT

Contractors engage in multiple construction projects to bolster their presence and influence within the industry, aiming to capitalize on benefits. The effective dissemination of green knowledge is paramount for project managers seeking sustainable outcomes and the reduction of environmental footprints in construction practices. This study presents a conceptual model delineating the transport of green knowledge across contractor projects, drawing parallels from transmembrane substance transport in cell biology. It identifies pivotal factors and forms of organizational collaboration crucial for facilitating green knowledge transfer, further illustrated through a comprehensive case study. The findings reveal that various project attributes such as green knowledge content difference, expressibility, embeddedness, attitude channel and participation energy significantly influence the modes of knowledge transfer. Active transfer mechanisms, categorized as knowledge pump and co-transfer, leverage project experience accumulation and external personnel as intermediaries. Passive transfer modes, comprising simple diffusion and facilitated diffusion, are determined by the value of green knowledge. Notably, the flow of green knowledge among engineering projects manifests as intersecting trajectories. This study elucidates the dynamics of green knowledge transfer, fostering heightened environmental consciousness within contractor entities, thereby reducing the risk of environmental degradation and elevating project sustainability performance.

Keywords: engineering projects, green knowledge, cell biology, transmembrane transport, knowledge transfer.

1 INTRODUCTION

Sustainable development of the construction industry faces significant challenges due to escalating energy consumption and environmental pollution. The process of rapid urbanization has contributed to a steady rise in carbon emissions within the construction sector, resulting in adverse effects on natural ecosystems across various stages of materials production, construction, and building operation [1]. As primary executors of engineering projects, contractors play a pivotal role in shaping construction practices, with management strategies and adoption of green technologies influencing environmental interference throughout project lifecycles. Embracing environmentally friendly concepts, curbing carbon footprint and pollution emissions are imperative for fostering green development within the construction realm [2]. Consequently, fulfilling environmental responsibilities transcends mere compliance with policy mandates for contractors; it is also a fundamental necessity to align with environmental imperatives and industry progression.

In the competitive construction market, contractors often engage in multiple projects to bolster revenue and enhance their standing, aiming to bolster competitiveness and influence. However, due to inherent disparities in project types, scales, and geographical locations, project managers often prioritize their company's platform and project-specific goals, overlooking the potential benefits of cross-project knowledge exchange. The mobility of project personnel can result in the loss of valuable knowledge that remains underutilized post-project completion, leading to challenges such as a dearth of innovative solutions, repetitive environmental harm, prolonged project durations, and increased costs. While project

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managers readily prioritize safety and cost-related knowledge, the significance of green knowledge may be overlooked, as the environmental impacts of engineering activities often manifest with a delay [3]. Consequently, there is a prevailing inclination to prioritize short-term objectives, potentially neglecting the long-term environmental consequences. However, the accumulation of unnoticed environmental issues can escalate into irreversible ecological damage, posing significant risks once they surpass the system's self-regulatory capacity. Addressing these challenges necessitates a concerted effort by companies to fulfil corporate social responsibilities, while project managers must heighten environmental consciousness and actively engage in the borrowing and dissemination of green knowledge to alleviate environmental burdens [4]. Facilitating the diffusion of green knowledge across multiple projects relies on establishing regular communication channels, enabling the sharing of valuable green insights, including the promotion of universal techniques and the transfer of project-specific experiences. Such initiatives play a pivotal role in enhancing environmental sustainability across construction endeavours.

The scope of green knowledge within engineering projects extends beyond mere material selection, construction technology updates, waste disposal strategies and interpretation of sanctioned cases. It embodies the dynamic traits of flow, dissemination, and transfer across organizational boundaries [5]. Following the exportation of green knowledge from an engineering project, it undergoes scrutiny and assimilation by other projects, wherein useful insights are identified, absorbed, and utilized as references for fostering sustainable practices within the project lifecycle. Notably, the sources of knowledge absorption in engineering projects extend beyond projects managed by contractors, encompassing stakeholders such as government bodies, the public, and suppliers. This study, while not categorically delineating the sources of green knowledge, primarily focuses on elucidating the process of its transfer. By drawing parallels between substance transfer across cellular membranes and green knowledge transport across projects, the study identifies key factors influencing green knowledge transfer among projects and discerns various types of organizational collaboration. Enriching our understanding of project-dimensional knowledge transfer factors through vivid descriptions. Diverging from mathematical analyses, the study employs case studies to elucidate the mechanisms of green knowledge transfer, translating the conceptual model into practical applications within the engineering domain. Ultimately, this study fosters a robust flow of green knowledge among engineering projects, thereby reinforcing contractors' internal environmental management practices, mitigating environmental risks, and catalyzing the green transformation of the construction industry at its frontline.

2 ELEMENTS ANALYSIS

Cells continuously survive and reproduce by interacting with the external environment, exchanging substances and nutrients through the cell membrane to specific locations. Serving as crucial structural boundaries, the cell membrane maintains a stable intracellular environment and regulates the passage of substances in and out of the cell [6]. Similar to the cell membrane, the organizational boundary of engineering projects delineates the separation between internal operations such as design, procurement, and engineering teams aimed at achieving project objectives, and external entities such as government agencies, the public, material suppliers, and technology research and development institutions, which play supervisory roles, engage in collaboration, or provide consulting services. Additionally, the implementation of other engineering projects also lies beyond the organizational boundaries of the project. This biofilm boundaries of the project are illustrated in Fig. 1. The organizational boundary functions as a discriminator, capable of discerning the type and volume of information transmitted, analyzing disparities in content, and selecting pertinent guidance knowledge for engineering practice. Green knowledge is recognized through this organizational boundary, then directed to the management team overseeing environmental performance, and subsequently disseminated to frontline operational staff in a timely manner. This process facilitates resource and information sharing, reducing environmental risks and enhancing work efficiency. Just like cell membranes, the organizational boundaries of engineering projects are selectively permeable, serving as a prerequisite for the transfer of green knowledge among projects.

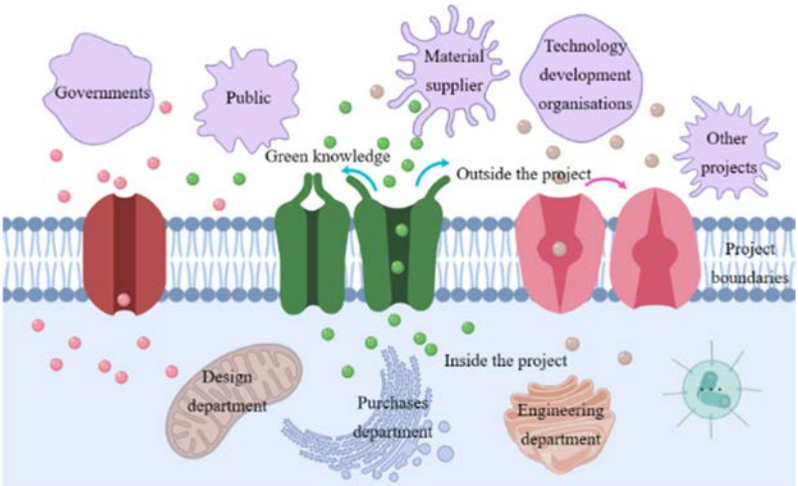

Figure 1: Biofilm boundaries of the project.

The direction of substance transport, whether through passive or active means, is influenced by the concentration gradient between the interior and exterior of the cell. Passive transport typically occurs from areas of high concentration to low concentration, whereas active transport operates in the opposite direction. Similarly, within engineering projects, the specificity of each project dictates that the green knowledge possessed by project management personnel will not entirely overlap. While universal adherence to regulations and policies establishes clear and environmentally friendly construction standards, the actual construction process may encounter ecological constraints such as geological soil compositions, plant and animal species diversity, and other environmental factors not comprehensively considered during pre-design and construction planning. In some cases, experimenting with new technologies may reduce carbon footprints and energy loss. Green knowledge derived from individual projects can serve as valuable references for others, helping to prevent similar issues and mitigate additional costs resulting from environmental damage. Regular project cycle meetings organized by contractors serve as vital conduits for the flow of green knowledge. Unlike substance transport across cell membranes driven by concentration differences, the transfer of green knowledge between projects occurs from those possessing specific green resources at a given moment to those with lower levels of knowledge in this area. This asymmetry offers an advantage, as the project receiving the knowledge benefits from a higher stock and quality of information compared to projects unfamiliar with such knowledge. The content difference in green knowledge between projects, reflecting the level at which green knowledge is assimilated, triggers its transfer and diffusion within the organization.

The attributes of substances significantly influence the conditions of transmembrane transport. For instance, lipid-soluble substances like oxygen can permeate the cell membrane without the need for carriers and without consuming additional energy. Conversely, charged ions and other substances are more prone to passing through the cell membrane with assistance. Similarly, green knowledge transferred between projects varies in clarity due to differences in content. Knowledge characterized by high expressiveness is transferred more efficiently, with the source of knowledge output swiftly disseminating to other projects. Consequently, recipient projects are better equipped to absorb such knowledge. For example, environmental regulations circulate rapidly among projects due to their high expressiveness and effective transfer medium. These regulations serve as a foundational reference for promoting sustainable construction practices. In contrast, green experiences gained through practical application require explanation to be recognized for transfer, slowing down the utilization of green knowledge. Thus, the transfer of green knowledge between projects is closely tied to the expressiveness of the knowledge itself.

Carrier proteins exhibit a high degree of selectivity for substances transported across cell membranes and play crucial roles in facilitated diffusion and active transport. Similarly, green knowledge between engineering projects becomes embedded within specific transfer media to facilitate cross-organizational flow, akin to carrier proteins, which possess both discriminatory and transport functions. When knowledge is embedded in project managers, communication between them facilitates knowledge transfer. Likewise, embedding knowledge within specific engineering projects enables the discovery of valuable green information through product research. Moreover, embedding knowledge within project conventions and best practices, the extent of its adoption significantly influences the level of knowledge transfer. Sub-relationship networks also play a role in carrying a portion of green knowledge. The process of expressing, transferring, and transmitting green knowledge in engineering projects necessitates the involvement of carrier proteins such as project managers, project products, conventions, best practices, and sub-relationship networks. Different categories and contents of green knowledge are combined with specific proteins to realize effective knowledge transfer.

Ion channels, integral membrane proteins, form hydrophilic channels facilitating ion transport across biological membranes. In their open state, ion transport initiates biochemical reactions, altering the electrochemical gradient of ions on both sides of the cell membrane. This process is crucial for material, energy, and signal conduction, characterized by ion-selectivity and gating mechanisms. Similarly, the successful transfer of green knowledge between engineering projects hinges on a profound understanding of sustainable development concepts within the engineering realm and the inclination of project managers to propagate green knowledge. Managers with positive attitudes towards green initiatives find it easier to engage in inter-organizational cross-boundary activities. Project management culture profoundly influences employee behaviour in project implementation. Higher environmental awareness among employees correlates with a greater likelihood of reducing non-environmentally friendly construction practices, fostering a stronger willingness to learn and transfer green knowledge, and enhancing receptivity to new knowledge. Analogous to cellular ion channels, project attitude channels exhibit selectivity regarding the type, quality, and capacity of transferred green knowledge. Moreover, these attitude channels remain open under external stimuli such as project reorganization and mergers, akin to gating mechanisms.

Just as cells require transmembrane transport of energy-consuming substances to sustain normal life activities, the sustainable construction of engineering projects necessitates organizational involvement in energy to facilitate the cross-project transfer of green knowledge. Identifying the structure and carrier of green knowledge, mitigating conflicting differences between various forms of project management, and establishing pathways for green knowledge transfer are crucial focal points in knowledge transfer endeavours. The level of knowledge internalization and spillover is influenced by the contributions and participation of project members, with green knowledge more likely to circulate between projects when there is high participation energy. Direct and indirect methods of energy supply within a project can complement each other based on the specific needs of the project, ultimately realizing the objective of knowledge transfer.

As a result, a comparison of the similarities between cellular transmembrane transport and green knowledge transfer across projects is shown in Table 1.

Table 1: Similarity elements for green knowledge transfer under cell biology.

Cellular substance transport	**Green knowledge transfer for engineering projects**	**Similarity**	**Role in transfer processes**
Concentration difference	Content difference	Unbalance	Triggering the occurrence of knowledge transfer and diffusion.
Physical attributes	Expressibility	Own attributes	Determining the level of difficulty and complexity of the knowledge to be transferred.
Carrier protein	Embeddedness	Specificity	Identifying agents of knowledge transfer.
Ion channel	Attitude channel	Selectivity, gating	Influencing the fluency of knowledge transfer.
Provide energy	Participation energy	Consumption	Guaranteeing smooth transfer processes.

3 TRANSFER MODES

3.1 Green knowledge passive transfer

In engineering projects, the reception of green knowledge without requiring the participation energy of organizational members is akin to a passive transfer process. This involves the influx of green knowledge from the external environment, characterized by high knowledge content, into the project. Depending on the presence or absence of carrier proteins, this process is further categorized into simple diffusion and facilitated diffusion. In practical engineering settings, this distinction is manifested by the flow of green knowledge embedded within mediums between projects. For instance, changes in project managers or the circulation of documents and policies serve as indicators of this flow. It is important to note that simple diffusion does not imply the dissemination of knowledge without any medium involvement. The determination of whether carrier proteins are involved hinges on the value of green knowledge transfer. Higher-value knowledge tends to have more mobile embedded mediums facilitating its transfer.

Low-value green knowledge lacks the capacity to supplement the dearth of green experience within engineering projects. Universal content neither demands additional learning efforts from project members to grasp nor serves as communicative green knowledge utilized by managers and frontline staff to broaden transmission scopes, as it fails to address practical project challenges. For instance, general green knowledge regarding proper construction waste disposal, wastewater management, and biodiversity preservation serves an educational purpose in regulating project personnel's behaviour. However, its shallow depth and inability to offer solutions to specific environmental threats in construction scenarios limit its mobility across engineering projects. Carrier proteins play a less significant role in transferring low-value green knowledge, corresponding more to simple diffusion. In contrast, high-value green knowledge injects fresh insights into project execution, demonstrating practical applicability and enhanced mobility. Knowledge-sharing endeavours often spotlight management processes or construction techniques for carbon reduction and environmental protection in specific contexts. Project personnel accumulate evidence of similar problems under particular theoretical frameworks to boost work efficiency when facing recurring environmental issues. Possessing high reference and borrowing value, such knowledge is readily transferred between projects. High-value green knowledge necessitates the engagement of carrier proteins and aligns with facilitated diffusion. The passive transfer process of green knowledge in engineering projects is expressed in cell biology as shown in Fig. 2.

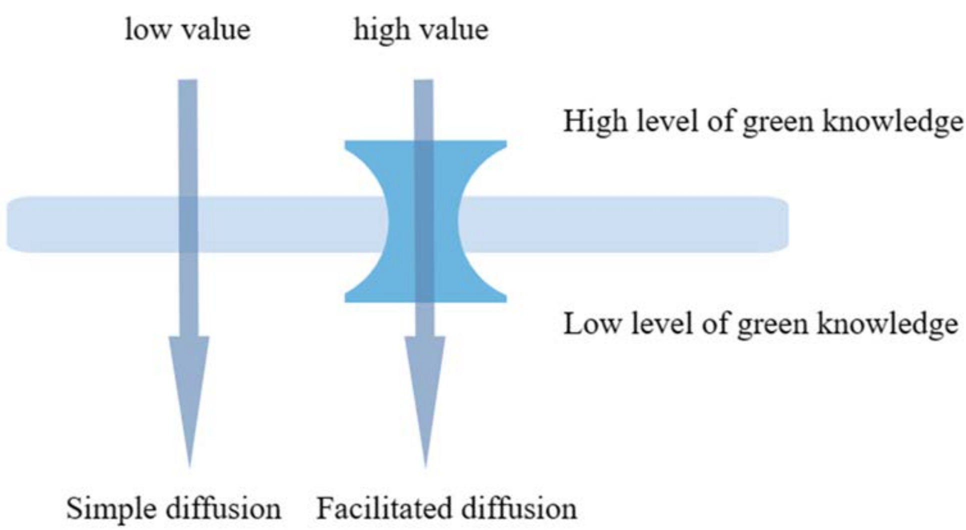

Figure 2: Green knowledge passive transfer processes.

3.2 Green knowledge active transfer

Green knowledge active transfer in engineering projects is categorized into knowledge pump and co-transfer based on the energy consumption of organizational participants. Knowledge pump involves direct supply by the project, while co-transfer occurs indirectly through project influence and external factors. Similar to passive transfer, knowledge flow in the same direction is absorbed from the outside world with high content to the inside of the organization, with carrier proteins and ion channels facilitating active knowledge transfer. In engineering practice, the driving force for project personnel to engage in green knowledge transfer, whether stemming from self-consciousness or external pressures, determines the manner in which green knowledge is actively transferred.

The geographical proximity of projects, shared project objectives, and mutual environmental concerns foster regular interactions among projects. Since environmental sustainability initiatives do not entail competing interests, entities with advanced green technologies and construction experience willingly transfer green knowledge to other related projects, resulting in a mutually beneficial outcome through knowledge sharing. For knowledge recipients, the investment of energy and time in accessing, understanding, and applying new methods relevant to their projects is significantly prolonged. Channels for expanding green knowledge, such as group trainings, expert lectures, and exchange seminars, require substantial organizational participant energy. However, there is a strong inclination towards self-study within projects due to the perceived benefits and practicality for enhancing environmental performance. Green knowledge transfer processes propelled by the project itself are termed the knowledge pump. The efficiency of green knowledge transport across projects is heightened when attitudinal channels remain open.

Another form of knowledge transfer involves external stakeholders, such as regular sampling inspections by governmental environmental inspectorates, public feedback, and technological advancements in research and development organizations. These activities allow project members to passively receive green knowledge, motivating efforts to strengthen knowledge acquisition and regulate construction behaviours within the project to avoid environmental sanctioning events. Co-transfer considers the impact of external subjects on green knowledge transfer. The project harnesses the energy of organizational participants to comply with regulations and address environmental vulnerabilities. New response plans are developed to meet external project requirements, enhancing the reference and application of green knowledge under external pressure. Just as with knowledge pumps, smooth attitudinal channels during co-transfers also bolster the efficiency of knowledge transport. Drawing on cell biology, the process of green knowledge active transfer in engineering projects is depicted in Fig. 3.

The resulting types of organizational collaboration for green knowledge transport across projects are shown in Table 2. Passive and active forms of transfer do not exist singularly and intersect with each other.

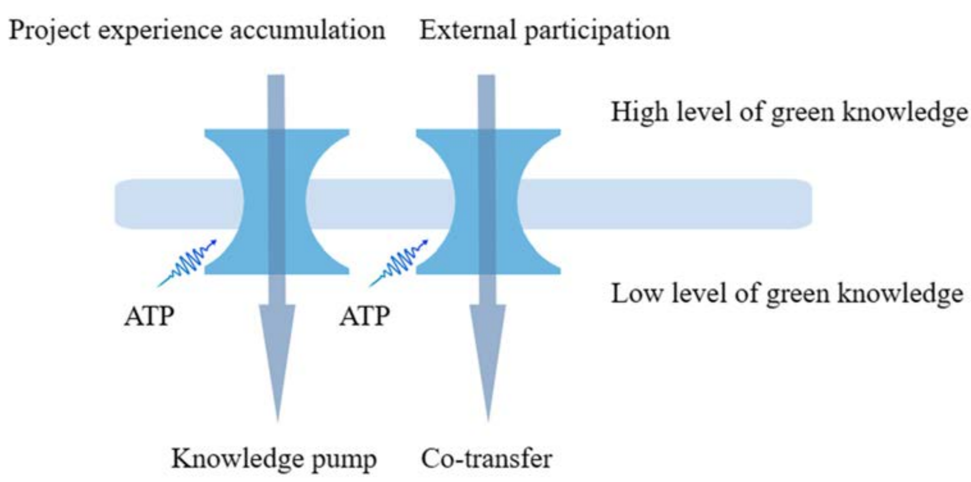

Figure 3: Green knowledge active transfer processes.

Table 2: Types of organizational collaboration for green knowledge transfer across projects.

Types of organizational collaboration	Specific divisions	Carrier protein	Energy consumption	Green knowledge transfer processes
Passive transfer	Simple diffusion	Unnecessary	Unnecessary	Low-value green knowledge flows
	Facilitated diffusion	Necessary	Unnecessary	High-value green knowledge flows
Active transfer	Knowledge pump	Necessary	Necessary	Transfer intermediary with project experience
	Co-transfer	Necessary	Necessary	Transfer intermediary with external participation

4 CASE STUDIES

Contractors are pivotal entities in the construction market, entrusted with significant engineering tasks. Frequently, a single contractor is involved in multiple projects concurrently. Consequently, the green knowledge garnered within one project has a propensity to permeate across other projects undertaken by the same contractor, a process heavily influenced by internal and external environmental factors. Using contractor A as an illustration, it is a local construction company specializing in medium-sized projects with full qualifications, organizes its ongoing projects into distinct design, procurement, and engineering departments to streamline operations. These departments serve as focal points that significantly influence green knowledge transfer within the project. Beyond the project boundaries, external entities such as government bodies, material suppliers, the public, and technology research and development organizations exert influence on the absorption and utilization of green knowledge. In the context of contractor A's three projects, the internal and external environments are depicted in Fig. 4.

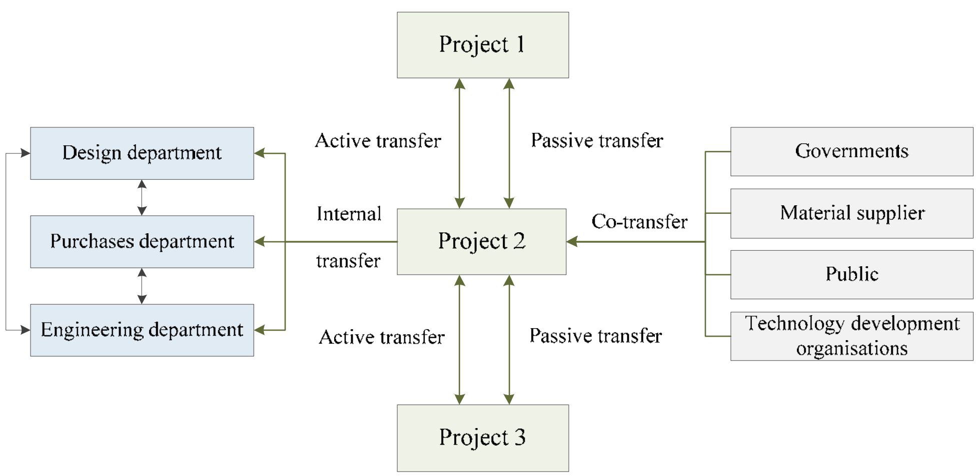

Figure 4: Green knowledge transfer in engineering projects.

Project 2, amidst its construction activities, accumulates a significant amount of green experience. Through regular inter-project meetings, it disseminates this knowledge to Projects 1 and 3 while also receiving green information from external sources. Upon evaluation, project 2 identifies and selects beneficial green knowledge, comprising universal knowledge with weak, low-value references, and guiding knowledge with strong, high-value references. This knowledge is then relayed to respective functional departments. In cases involving unfamiliar technical methods, training sessions are organized for relevant personnel across departments, with experts invited to address technical challenges.

Additionally, external factors such as governmental environmental authorities strengthening the project's compliance with environmental policies as per regulations, the need to rectify environmental defects impacting public quality of life, and changes in material production cycles and technological advancements leading to heightened learning costs further enhance and expand the application scenarios of green knowledge.

Project 2 actively transfers green knowledge during information exchanges with external stakeholders, allowing for the coexistence of both active and passive transfer modes. Similarly, Projects 1 and 3 actively engage in the flow of green knowledge within Contractor A's project portfolio, serving as both contributors and recipients of green knowledge exchange.

5 CONCLUSIONS

The transfer of green knowledge across organizational boundaries in engineering projects is influenced by both internal and external factors, akin to the transmembrane transport of cellular substances. Through similarity analysis, it becomes evident that the content difference, expressibility, embeddedness, attitude channels, and participation energy of green knowledge play varied roles in the knowledge transfer process. Based on these attributes and the involved elements, the flow of green knowledge is segmented into two distinct forms of organizational collaboration: active and passive transfer. Active transfer, which entails energy expenditure from organizational participants, encompasses two forms: knowledge pump, driven by direct willingness stemming from project experience accumulation, and co-transfer, prompted by external environmental pressures. The attitude channel facilitates the flow of green knowledge under active transfer. In contrast, passive transfer occurs without energy consumption. If the green knowledge holds low value and lacks mobility within its embedded medium, it undergoes simple diffusion. Conversely, high-value green knowledge corresponds to facilitated diffusion. Under both forms of organizational collaboration, the green knowledge content difference serves as the catalyst for knowledge transfer, flowing from the side with higher knowledge content to the other. Additionally, the expressiveness of green knowledge dictates the difficulty and complexity of its transfer. The mode of green knowledge transfer across project boundaries transcends multiple elements. While this study draws inspiration from cell biology, the conceptual model of knowledge transfer does not mirror the real transmembrane transport of substances. Therefore, it can be enhanced by incorporating elements such as membrane potential and ion transport rate for quantitative analysis of green knowledge rate change between projects, further guiding sustainable construction practices.

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