

Tao, Sha; Pang, Xinyi; Qiu, Yumin; Xu, Qingshuang; Xue, Peng

Article

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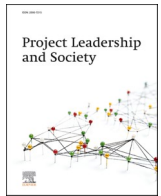
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Empirical Research Paper

Green innovation in megaprojects: A capacity-based analysis of the Shenzhong Link Project in China

Sha Tao^a, Xinyi Pang^a, Yumin Qiu^{b,*}, Qingshuang Xu^c, Peng Xue^b^a School of Management and Engineering, Nanjing University, Nanjing, 210093, China^b School of Accountancy, Nanjing University of Finance and Economics, Nanjing, 210023, China^c Shenzhen-Zhongshan Link Administration Center, Zhongshan, 528400, China

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ABSTRACT

Growing environmental challenges and expanding megaprojects have necessitated green transformation of the construction industry. This paper takes the Shenzhong Link Project as an example to explore the capacities required for achieving the goal of green innovation, as well as its micro-expression and behavioral path. We begin with the idea that megaprojects are complex, and then we dissect the capacities from both soft and hard system levels, categorizing them into basic and composite capacities. Then, we form the integration of capacities to realize green innovation of megaprojects. Green development is an essential prerequisite for high-quality megaproject development. Our approach provides a guided study on how to enhance the role of micro-internal drivers in the management of attaining green innovation in megaprojects to help project managers achieve green performance and promote quality development.

1. Introduction

The rapid growth of China's construction industry coincided with the country's booming economy and urban population, resulting in an increasing number of megaprojects. However, data reveals that the construction industry has exerted a considerable negative impact on environmental conservation and sustainable development worldwide in the 21st century (Cao et al., 2022). Based on the report of the Global Alliance for Buildings and Construction, the buildings and construction sector accounted for 36% of global end-use energy consumption and 37% of global energy-related CO₂ emissions in 2020. Environmental risks associated with the construction industry have become a worldwide concern. The traditional construction model falls short of current development needs, so countries hope to solve this problem by promoting sustainable practices and launching green initiatives. The recent surge in megaprojects promotes economic development but significantly impacts its surrounding social environment, energy consumption, and ecosystems. This has heightened the importance of research on green innovation. Therefore, countries worldwide are now prioritizing the study of how to enhance green development in the construction industry with the intention of bringing about its transformation and upgrading (Amiril et al., 2014).

There are various concepts of green development, such as green economy, green growth, etc. These concepts have a common fundamental goal despite being expressed differently. i.e., to harmonizing and integrating circular economy development and ecological environmental protection (Hu et al., 2003). In China, green development concept has been considered as an inheritance of the theory of sustainable development, representing the second generation of the concept; it has more of its focus on the necessity of green transformation than on supplementary adjustments to the existing development model (Hu and Zhou, 2014). Green innovation is a crucial way to achieve sustainable development, as it effectively reduces emission reduction costs, minimizes pollution, enhances ecosystems, and supports sustainability (Hong et al., 2021). Further building on the foundation of sustainable development, in 2017 China launched a new concept of "high-quality development" to promote socioeconomic development. This includes comprehensively improving the quality and benefits of development in five aspects: economic, social, environmental, innovation and security, which will be integrated into project activities. (Ying et al., 2024). That means there are increasing demands and expectations for green development. Green innovation is indispensable for realizing high-quality development. China vigorously promotes green buildings in cities for energy conservation and emission reduction, and attaches great

* Corresponding author.

E-mail addresses: ts@nju.edu.cn (S. Tao), pxy15261822008@163.com (X. Pang), ymqiu@nufe.edu.cn (Y. Qiu), xu_qingshuang@126.com (Q. Xu), 3072904427@qq.com (P. Xue).<https://doi.org/10.1016/j.plas.2024.100144>

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significance to the green development, transformation, innovation and upgrading of the construction industry (Li et al., 2022). Nevertheless, its construction industry lags behind those of developed countries in green development and faces sluggish green transition, with no significant and sustained decline in total energy consumption yet. The goal of high-quality development remains unfulfilled.

Reviewing the current situation of China's research on the green development of the construction industry internationally, green buildings are thought to be an essential strategy to mitigate the detrimental effects of construction activities. They refer to buildings that offer environmental kindness, energy savings, pollution reduction, healthy residential environments, and comfortable utilization experiences throughout the asset's whole lifecycle. Some learners have started studying related fields or specific contents in order to realize green buildings, such as construction technology (Lu et al., 2017), assessment frameworks (Yang et al., 2017), and the current status of green buildings (Huang et al., 2021). Others have researched pollution issues during construction, including evaluating criteria for green construction (Li et al., 2023) and applying BIM in green construction (Yang et al., 2023). Scholars are also exploring the external drivers for realizing green innovation in megaprojects, focusing on the impact of government regulation on accomplishing this goal (Eghbali et al., 2022; Liu et al., 2020). However, most of the articles above have their focus on the technology and application criteria or macro-level evaluation systems for green innovation in engineering construction. As projects increase in scale and complexity, achieving changes and enhancement in the construction and engineering industry also requires true green innovation and development. This includes green innovation in technology, processes, materials, and other aspects of construction, as well as necessary external drivers. Additionally, it's vital to enhance the internal micro-drive capacity throughout a project's lifecycle, hence the need for new quality productivity to help transform and upgrade the construction industry.

Countries worldwide aim to transform and upgrade their construction industry, especially megaprojects, with green innovation, but no effective solution currently exists. This study uses China's Shenzhong Link (SZL) Project as a case study; it is a large-scale transportation infrastructure project that exemplifies multi-disciplinary complexity and construction challenges at the cutting edge of global standards. Moreover, the whole process of its construction fully embodies the concept of green innovation and development, offering a model for the green innovation of major projects in China and even globally. This study aims to examine the micro-expression and formation path of the capacities of megaprojects to attain the goal of green innovation based on the SZL Project which has yielded certain outcomes in engineering green innovation. To this end, we composed the following two questions:

- i) What are the megaproject participants' capacities in achieving green goals?
- ii) What are the origins and mechanisms of action of these capacities?

We carried out a case study on the SZL Project. This project fully implements the green innovative development idea in the entire engineering construction process and attains green performance; by virtue of its requirements of development, criteria of construction, and scale of construction, it has the construction conditions and background of realizing the green development of megaprojects. Through our investigation, research and analysis, we proposed nine key capacities to achieve green performance, split them into both basic and composite capacities, and lastly acknowledged the integration of these capacities, and with the integrated capacity, the SZL Project attained green innovation and green performance.

To be specific, this paper begins by reviewing available literature on achieving green performance, existing research on green innovation and related corporate capacities implications, it finds that most existing

research concentrates on the physical level of technology or micro external capacities, with little focus on the micro internal capabilities of individuals who accomplish green innovation. Then, the paper proceeds to outline the case data and methodology, followed by giving the constituents of the capacities that are part of our analysis' summary. Its final section discusses the advantages and disadvantages of the strategy we chose and weighs our results against existing research.

2. Literature review

2.1. Green development in the construction industry

Many scholars have already done research with the aim to attain green performance in the construction industry during its rapid development period. Due to the extensive mode of traditional construction and the limited environmental consciousness of site personnel and management teams, the on-site construction phase has been considered as the worst stage in practicing the green construction view (Hou et al., 2018). Consequently, there are a large number of studies carried out for the greening of the construction stage, setting their focus on the meaning of green construction, the model of management, and the evaluation of green construction (Wu et al., 2019; Tam et al., 2004). Following the advancement of construction levels, technology and concepts, it has become clear that green control during the construction stage alone is insufficient, and the idea of green building has emerged, emphasizing green sustainability throughout the whole lifecycle. In order to confirm the benefits of using green buildings, some scholars started to examine the cost-effectiveness of green buildings and the associated computations. These analyses were based on various factors that influence the building costs composition, and contrasted with the comprehensive benefits of traditional ordinary buildings (Coma et al., 2017).

Further, in terms of applied technologies for green buildings, Mei et al (2021) proposed a BIM-based framework that shouldered relevant managers to save on concrete formwork works' cost and minimize wastage of material. For further expansion of its application, Shukra and Zhou (2021) suggested a new conceptual framework for integrating green building parameters, BIM tools and green building assessment tools into the life cycle of a project to increase sustainability in the architecture, engineering and construction sectors. While the development of green building has been underway for quite some time, its coverage and application of technology remain limited. Therefore some scholars have investigated the underlying causes of this issue. Taking Ghana as an example, Chan et al. (2018) carried out a survey on the obstacles against the adoption of green building technologies in developing countries and suggested five categories of obstacles to development, providing a reference for further application of green building technologies in developing countries. Hammond et al. (2021) showed that the reluctance of owner-side adoption of green buildings is due to the process of making decisions through knowledge from behavioral game theory, the idea of finite rationality, and prospect theory, and suggested a theoretical model to try to solve such problems. In addition to this, many studies have investigated the importance of project management or stakeholders in achieving green performance and sustainability. For example, Jesse et al. (2017) suggested that an alliance model with a clear incentive model can promote sustainability and activate partners to develop innovative opportunities, thus promoting economic, environmental and social sustainability.

It is evident that at the level of acknowledging the green or sustainable development of the construction industry, most of the research has its focus on environmental gains, innovative design, construction technology and techniques of project management, and most of the research is conducted at the macro level, lacking explorations of the relevant competencies of the managers and participants.

2.2. Project innovation and green capacity

During the process of achieving green innovation in the construction industry, reliance on technological or evaluation systems developments is insufficient. The process of construction is essentially a human production management process, and a competent project manager is vital to the accomplishment of a project (Hwang and Ng, 2013). Therefore, thorough research is also a requirement on the capacity of participants to achieve innovative, green development goals. Chen et al. (2008) employed two main traditional strategies, worker-oriented and job-oriented, to distinguish project management competencies. The conclusion was that there is a need to have the capacity to plan and control, coordinate, and develop. However, as engineering construction appears to be increasingly rigid and diversified, it is much difficult to attain the green performance of large-scale projects in the construction industry, and project managers who want to acknowledge green innovation are required to improve their capacities to attain sustainability.

We can split green innovation into two aspects, "green", and "innovation". They can be understood as innovation in the whole process of production and operation considering the priority of ecological aims and rational utilization of resources. It is mainly reflected in the product and service innovation, production link saving, business process efficiency and marketing means of environmental protection (Horbach and Rennings, 2013), meaning that it includes not only technological and process innovation but also innovative transformations in the entire production management process. Green innovation is now recognized as a key competitive advantage for enterprises, and therefore scholars have researched the key factors that enable enterprises to develop green innovation capacities. Based on enterprise management, Xue et al. (2019) suggested that enterprises' ability to absorb can effectively enhance their ability of green innovation, and in turn, it advocates enterprises' performance. Li et al. (2019) showed that the green technological innovation ability of enterprises has a substantial benefit on enhancing the competitiveness of enterprises, which can contribute to the enhancement of enterprise performance, through the hierarchical regression analysis of energy saving and environmental conservation data of listed enterprises in China. It in turn positively contributes to environmental performance. Mao and Lu (2023) showed that big data management capacities can effectively enhance the green innovation capacities of enterprises with a positive impact. Further focusing on the construction industry, there lacks research on the capacities of green innovation, but some scholars have probed into the competencies related to the innovation or the management of megaprojects. Li et al. (2019) suggested a multilevel organizational framework using the theory of organizational behavior as a starting point, emphasizing the organization's significance for the management of large-scale projects. Zhou et al. (2018) suggested that intelligent means are important for solving the management, collaboration and coordination difficulties in the construction industry. Chen et al. (2008) viewed large-scale projects as a vital innovation ecosystem, and to innovate this ecosystem, they identified the formation of leaders of the ecosystem and cooperation, emphasizing the importance of organizational and collaborative capacities. Their thorough research of the complexity of large-scale engineering innovation management challenges further highlighted the significance of the coordination and cooperation among innovation subjects. Overall, most current research on managers' capacities to attain green innovation or green performance of projects is relatively fragmented and lacks systematic, thorough analysis.

In summary, based on existing literature, there are many studies focusing on how to attain green performance of technology, strategies, models, evaluation and other aspects in the construction industry, with little attention paid to the exploration of the capacities of management personnel in contributing to green innovation. Only in the enterprise management field, some scholars explore capacities in the construction industry. The micro-expression and systematic description of managers' capacities in the construction industry are still missing. Therefore, this

paper shows the micro-expression of the capacity of large-scale complex projects to attain green innovation and its path of formation from the actual research of the SZL Project. It can shoulder managers of projects in the construction industry to enhance their capacity and cognition of mastering green innovation.

3. Data and methodology

In this paper, we preferred the case of the SZL Project for our case study. This is because that, firstly, the background and intention of the construction of the SZL meet the requirements of green innovation development, and secondly, we had the unusual research opportunity of accessing the top management of the Management Center of the SZL and the project managers responsible for the different parts of the SZL. Besides, this access offered us a number of chances to enhance our comprehension of the main factors that require to be present in order to acquire green innovation in engineering construction and provided conceptual knowledge of how project managers can better enhance their capacities in various fields of their projects in order to attain green innovation.

3.1. Data collection

Located in the heart of the Guangdong-Hong Kong-Macao Greater Bay Area, the SZL Project is a world-class cross-sea cluster project with a total length of 23.974 km, integrating "bridge, island, tunnel and underwater interchange".

First, regarding construction scale, the SZL Project is a crucial transportation link connecting the city clusters on both east and west sides of the Pearl River Estuary. The construction process involves multiple parties, including construction personnel, government departments, environmental protection departments, and so on. Even a minor issue can involve dozens of teams and hundreds of participants, making coordination and efficient implementation extremely challenging. Second, in terms of construction requirements, the SZL Project tackles some of the world's most difficult issues. For example, the tunnel construction faces five major technical challenges: "ultra-wide, variable width, deep burial, large amount of siltation, and unstable stratum in the area of sand mining pits". These technical hurdles are unprecedented and must be addressed while minimizing impact on the marine environment. Hence the whole construction process is of great complexity. In addition, the construction environment itself is highly complicated. Before construction, route selection must consider the survival of white dolphins; during construction, the process must handle changes in the marine environment, typhoons and other natural disasters; after construction, the project contends with complex marine conditions such as long-term exposure to sunlight and high salt concentrations.

In general, unlike general projects, the SZL Project has larger scale and faces much complicated construction environment, more comprehensive technical challenges, and more stringent ecological standards. Attaining green development and green performance in this project requires more than merely adopting eco-friendly materials or techniques. It involves a holistic approach to innovation across various aspects and levels throughout the whole process and means of green development, as well as optimum ways to improve environment and social benefits and maximize greening and intensive savings while ensuring project quality.

Therefore, in order to explore how the SZL Project has attained green innovation and arrived at green performance, we collected data that started in 2015 when we made contact with the head of the SZL Management Center, whose role is enhancing and managing the SZL Project. The senior management team of the Management Center comprises a chairman, three directors, three deputy directors, and four chief engineers; the project teams also include a technical management team, a safety and security team, and an administrative team.

Data collection consisted of three parts: semi-structured interviews,

archived data, and participant observation, as shown in Table 1.

3.1.1. Semi-structured interviews

From 2015 to 2023, we employed pure communication and cooperation with the SZL Management Center to extract information through semi-structured interviews. Firstly, we interviewed the head of the SZL Management Center at least once, and we also carried out five interviews with the directors and the chief engineers, and many interviews with ordinary employees of the SZL Management Center. These interviews helped us understand the staff management, organization, processes, initiatives, and implications of the SZL Project in attaining green development goals. Secondly, we interviewed the designers and technicians who participated in SZL Project. Green technological innovations in the physical construction of the project are compulsory for attaining green performance, and hence their opinions are also very crucial in how to attain the green innovation goals.

Each interview was to comprehend what aspects, perspectives, and practices were employed in order to attain green development and green performance during the SZL Project. We established an interview protocol based on previous literature, with its focus on the practical procedures and impacts of attaining green innovation in the construction of megaprojects. The interview protocol entailed few questions based on three themes: (i) how to attain green innovation and green construction goals throughout the construction process; (ii) the opinions on main elements that managers require in order to attain green innovation; (iii) the opinions on key aspects that need to be conducted at the technical level to attain green innovation. Example questions are as follows: a) What challenges have been encountered in managing attaining green and innovative development processes? b) What preparations have been made to attain green and innovative development? c) What procedures of construction will be involved in these preparations?

3.1.2. Archived data

To enhance data accuracy and the resilience of conceptual knowledge, we obtained the archive sources of the SZL Management Center, including the comparison, feasibility technical and management reports from the beginning of the design and the feasibility reports, construction reports and so on during the construction process from 2015 to 2023, as detailed in Table 1. Also, we viewed the proceedings of project working group meetings, design change logs, special construction plans, and special journals throughout the construction process, and made a summary. In addition to the information in internal project documents and

Table 1
Data sources between 2015 and 2023.

Sources	Numbers
Interviewees	
Director of the SZL Management Center	2
Chief Engineer of the SZL Management Center	5
Staff of the SZL Management Center	12
Designers and builders	6
Technical team members	8
File records	
General Report on the Construction of SZL	4
Feasibility research reports	8
Feasibility reports	15
Specialized construction programs	25
Specialized journals	16
Proceedings	28
Patent application files	8
Interviews made by newspapers	45
Observations	
Design review meetings	Sporadic 3
Technological review meetings	Sporadic 6
Construction plan review meetings	Sporadic 12
Observation at the construction sites (2–5 h)	Sporadic 31 (days)

Note: Total number of interviewees: 33; file records: 149; observation reports: 52.

interview reports, we collected data from professional media, newspaper articles, interviews with the chief engineers and others, and academic papers published by engineers and managers.

3.1.3. Participant observation

From 2015 to 2023, we carried out participant observation within the SZL Project organization, including on-site tours, showing up in meetings as a note-taker, etc. The purpose is to experience the endeavors and impacts of SZL practically in attaining green innovations through practice, and to extract more information and learn more about the keys to influencing green performance.

3.2. Research methodology

Our study adopts a case study approach because case studies are fashioned to answer the "what", "where", and "how" questions of a research question (Kyburz-Graber, 2004). This can be used to elaborate, describe, or explore events or phenomena that occur on a day-to-day basis (Yin RK, 2009), can allow for thorough, multifaceted explorations of complex issues in real life contexts (Crowe et al., 2011), and can capture less tangible processes from a number of viewpoints (Eisenhardt, 1989). In particular, coming up with theories from case studies has certain advantages: (i) the possibility of generating new theories; (ii) the likelihood that emerging theories will be testable and that their construction will be measured easily; (iii) the high likelihood that the final theories will be realistically based due to the theory construction process being closely related to the evidence used to make them (Eisenhardt, 1989); (iv) unlike multi-case studies, single-case study emphasizes the extremity or uniqueness of the research object, which highlights the special scenarios of the research problem, fully explores case data and its underlying meaning, provides an in-depth account of the case story, and further reflects the researcher's creativity. The objective of this paper is to examine the background, purpose, process and impact of attaining green innovation in SZL, and then present the main elements to project managers in order to attain green innovation from multiple aspects and angles, create a project management capacity system, and then enhance the theoretical development of engineering construction to attain green performance.

On the other hand, the reviews of available literature have called for the employment of a case study strategy to provide a thorough study of the determinants of whether or not an organization's achievement of transformation or innovation management can be successful (Errida, 2021). The case study research is one of the most known strategies in relevant studies on project management. For example, some scholars have employed the case study strategy to identify the determinants of success in organizational change management (Errida, 2021), and some have adopted it to study project organizations' evolution, and how organizations can enhance their project capacities (Kwak, 2015). This confirms the viability of employing the case study methodology to examine the research questions in this paper, and lays a theoretical foundation for thorough research in this paper.

3.3. Data analysis

The research in this paper employed a single case study and collected data through qualitative research methods, i.e., semi-structured interviews, archived data collection, and participant observation. This methodology offers advantages such as studying contemporary phenomena in a real-life context, taking the construction project as a single subject of analysis, and building a fact-based model based on fieldwork, with a view to effectively addressing various issues in organizational management (Butt et al., 2016). Therefore, underpinned by this methodology, the following analytical steps are taken to explore the capacity of the SZL Project to achieve green development goals.

Step 1: Collect and analyze the archival materials provided by the SZL Project teams, including the initial design scheme and technical analysis report, as well as the special programs developed throughout the construction process. Preliminarily clarifies the background, objectives, construction priorities and overall direction of the green development of the SZL Project, laying a solid foundation for the next step of observation and interviews.

Step 2: After the preliminary data analysis, the researchers visited the construction site and participated in important project reporting meetings. They focused on recording relevant content about the realization of green innovation development obtained from the archival materials, collecting data addressing three key questions: Why green innovation should be carried out? What is the work done to realize the goal of green innovation? What were the results obtained?

Step 3: In-depth semi-structured interviews were conducted to complement the archived data and participant observations. Based on the content obtained from the previous steps, questions were broadly organized to verify the consistency between the actual participants and the recorded documents. The broad interview questions are shown in the Appendix. Content analysis techniques were used for the data obtained from the semi-structured interviews. This involved dividing the interviews according to a set number of identified themes. Content with common characteristics was continually collected and grouped during the analysis process, thus streamlining the large amount of raw interview data into a series of independent and manageable datasets. Thus, the important capacity of realizing the goal of green and innovative development of the SZL can be distilled.

Step 4: The research of this paper took place in the middle of the engineering process. Therefore, the above steps were continuously repeated according to the development of time. Gradual refinements and additional interviews were conducted iteratively to finalize the completed capacity architecture.

4. Case studies

As mentioned above, constant scientific and technological advances, along with economic growth, have led to a boom in China's engineering construction sector and larger project scales. The complexity of project challenges continues to grow, with increasingly stringent requirements. Consequently, researchers are focusing on how to resolve the challenges posed by the ever-changing environment in project management.

Firstly, we commence with the concept of "engineering", which refers to the process of making artifacts on the basis of certain intentions, i.e., the process of creating artifacts from "virtual engineering" to "physical engineering" by turning one's understanding of the distinctiveness and authentic essence of a project into the objective, plan and method of the distinct entity of the project. This procedure calls for requirements pertaining to the behavior of the main body of management during the entity formation process, in addition to a program for the formation of the engineering entity's shape. This implies that we can split the basic activities of the end formation of the engineering entity into two parts. One part is a major project hard system, that is, the major project management object, the final formation of the building entity; the other is a major project soft system, that is, the major project management system, how to make impactful management of the process of creating things (Sheng, 2020). These two parts, mutually coupled in management, constitute a complex system. In order to attain the aims and requirements of the construction, coordinating the management of these two parts is required for an efficient and well-organized setup.

Therefore, to attain the objective of green innovation in engineering and construction, it is essential to understand not only external drivers but also internal micro-drivers. Specifically, what specific capacities are needed from the participants, and how do these capacities enable them to fulfill their roles and accomplish objectives? Also, this paper begins

with these two parts and combines the specific typical case of SZL Project. It summarizes and analyzes the data from Chapter III, identifies nine major capacities, and splits them into basic capacities and composite capacities. It eventually acknowledges the combination of these capacities, and presents the micro-performance of these capacities in the practice of the whole project as well as the formation path. Table 2 highlights the correspondence between some data (phrases or textual information) and the capacities presented in this paper.

4.1. Basic capacities

Basic capacities are the most fundamental abilities or capabilities required for green innovation in engineering and construction management. They are the foundation and starting point for attaining green innovation. Further innovation and development can only proceed effectively with these basic capacities in place. They include technological, absorptive and transformational capabilities, and organizational, synergistic, and implementation abilities.

4.1.1. Physical-level basis capacities

4.1.1.1. *Technological capacity.* Traditional engineering and construction processes often result in significant energy consumption, resource wastage, exhaust waste, etc. This will in turn put great strain on the surrounding environment and project budgets, and give rise to key technical concerns and problems in engineering construction. In order to

Table 2
Presentation of nine capacities.

Capacity	Data Information
Synergistic ability	In order to assist in the scientific and environmentally friendly disposal of dredged materials for the SZL, the provincial government has coordinated the disposal of 60 million cubic meters of dredged materials assigned by Guangzhou City, Zhongshan City, Shenzhen City, Dongguan City and the South China Sea Sub-bureau of the (former) State Oceanic Administration
Organizational ability	Organization of numerous meetings and discussions to minimize the environmental impact of route selection
Implementation ability	Rapid response from all parties Ensure the timely response and implementation of the instructions issued by the Management Centre by each department and team
Technological capacity	Formed a set of green construction technology systems for SZL island tunnels Tunnel ventilation and lighting generate huge energy consumption during the operation period, and the adoption of energy-saving and emission reduction technologies for tunnel ventilation and lighting has great potential for application
Transformational capacity	SZL further upgraded on the basis of automation of Hong Kong-Zhuhai-Macao Bridge workstations, and realized zero breakthrough in intelligent manufacturing with Internet + BIM technology + intelligent robots
Absorptive capacity	Fully draw on the experience of the Hong Kong-Zhuhai-Macao Bridge in respect of the adoption of the scheme and the place of construction of parts and components
Digital-intelligence capacity	Complemented by the adoption of the Smart Maritime System Digitalization of data monitoring Make full use of digital means and intelligent platform systems to detect and safeguard each phase
Innovative capacity	Many of the issues are not referenced in the current project construction To optimize and innovate on the basis of existing processes, taking into account the impact of the complex environment of the ocean in the long term
Mindfulness ability	How to avoid the Chinese White Dolphin Sanctuary is the first and foremost consideration in route selection Reducing impacts on the marine environment needs to be prioritized

The following sections explain the proposed nine capacities in detail.

attain the green objective, it is necessary to fundamentally transform energy-intensive processes, methods, equipment, materials, etc. Through technological capacity, the SZL Project in the construction of artificial islands and tunnels faced many special circumstances such as ultra-wide, deep-buried tunnels and large amount of back-silting, and was impacted by the Lingding Channel Bridge sea environment, soft cover and many other complex environmental effects. For the necessary purpose of attaining green building in these circumstances and minimizing the effect on the marine environment, pollution emissions and so on, the managers of the project investigate innovative green technologies for various processes and aspects, including design, installation, construction, dredging and soil treatment. It develops intelligent manufacturing and intelligent pouring systems, foundation treatment technology, dredging technology using rakes and suction vessels, etc. These innovations help attain ecological and environmental protection, pollution reduction, carbon reduction, synergy and other green goals, and lead the development of science and technology simultaneously.

In short, technological capacity refers to the process of the owner and the construction contractor hiring appropriate technical experts, in light of technical issues and challenges that could have a significant impact on green development requirements, to carry out technological research, technological innovation research and development, and practical and efficient application, with an aim to fundamentally attain the reduction of energy consumption and waste emissions, ecological environment conservation, and other green innovation and development objectives.

4.1.1.2. Absorptive capacity. Based on business management, absorptive capacity is the capacity of a company to acknowledge the new information value, assimilate it, and apply it for business purposes, also in the context of engineering to achieve innovation greenness. To attain the goal of green and innovative development, SZL Project absorbs and combines the existing level of green construction technology and application solutions. Then in the present time, the digital and information level is constantly improving, the internet of things (IoT), intelligent sensing, big data and other new information is constantly emerging. Reasonable use of intelligent means can effectively enhance project efficiency. Also, the SZL Project, based on the BIM, intelligent sensing and the IoT technology, developed a whole-process intelligent information management system for steel shell immersed pipe concrete pouring, covering the production of concrete, transportation, pouring, and testing. Using big data to shoulder decision making, it can attain high-quality, efficient, intelligent and refined management with the intelligent assignment of tasks in each link of immersed pipe prefabrication, real-time monitoring and recording and rapid positioning of construction defects and automatic generation of reports, in order to attain the information-based management and control of the whole process of pipe section prefabrication, enhance the quality of concrete pouring, reduce the loss of concrete pouring process, optimize the allocation of resources, reduce costs and increase efficiency.

To put it simply, in the engineering construction process, when the existing capacity in the current engineering construction cannot realize green development, the decision-making party or research and development team must leverage absorptive capacity to identify and assimilate the value of new information. It will be possible to apply effective means to the current engineering construction and provide reliable support programs and safeguards for attaining the green innovation of the project.

4.1.1.3. Transformational capacity. Today's society environment is changing frequently. Attaining green innovation and development of engineering construction necessitates the effective integration and transformation of rigid information in society and current abilities. From there, we can find the point of breakthrough of green innovation and practice it, acknowledging the process of green construction from nothing to something, from complexity to simplicity. During the

construction of the tube section of the SZL Project, if the quality indexes of DCM pile verticality and cement slurry performance are not strictly controlled, the quality of pile formation will be affected, causing excessive settlement of the local tube section. Therefore, the SZL Project adopts an integration of the existing foundation treatment program, DCM composite foundation + combined foundation bed and natural foundation + combined foundation bed programs, which increased the quality assurance rate of piling to 95%, greatly minimized the reworking risk, and effectively reduced the waste of resources and cost consumption.

Generally, engineers and decision-makers must rely on the current means of transformation and upgrading because the current level of technology or program means cannot meet the current needs of engineering and construction. That is, they should effectively streamline the transformation and upgrading of dynamically changing or incomplete knowledge, and internalize the ability of other teams, so as to find the key to innovation and keep diversifying innovation processes and programs.

4.1.2. Management-level basic capacities

4.1.2.1. Organizational ability. It is frequently not within the power of one party to innovate, change, transform, upgrade, but it is a team or a company. The whole life cycle of engineering construction will involve a large number of participants, ranging from small construction workers to large contractors, and design teams. If it wants to attain green changes or upgrades, to a certain extent, it is dependent on the management team's leadership and organizational capacity, through coordination between the parties concerned to carry out research on different issues and effective organizational framework for effective management of the day-to-day construction work. Green routing was incorporated into the routing design as a crucial controlling index, and a full range of corridor belts and routing options were chosen based on the idea of green highway along the whole route at the beginning of the design of the SZL Project. In order to improve the selection process, the Department of Transport of Guangdong Province commissioned the Chinese Capital Group, the China Railway Eryuan Engineering Group Co., Ltd., the China Railway Siyuan Survey and Design Group Co., Ltd. and other professionals to participate in the entire program selection process. Through organizing and conducting program selection meetings often, after more than a decade of repeated argumentation and selection, an engineering feasible, environmentally friendly and reasonable route plan was finalized, which avoids the Chinese white dolphin migration area to the maximum extent possible, minimizes the dredging volume, reduces the effect on the sensitive points of the marine environment and interference with the ecological environment along the route, and maximizes the green gains and green innovation.

The entire selection process fully demonstrates the leadership and organizational ability of the Department of Transport of Guangdong Province. In other words, organizational ability pertains to the entire process of engineering construction. When one's strength is insufficient to solve an issue or when multi-party collaboration is required, the decision-maker must bring together the pertinent parties by developing an appropriate organizational structure, and identifying appropriate management personnel or organizations to conduct seminars, decision-making meetings, and other activities. This will enhance multi-party collaboration's effectiveness in coming up with ideas and achieving green innovation.

4.1.2.2. Synergistic ability. As mentioned above, the construction process involves many participants, especially given the constant expansion of the construction scale; consequently, the number of participants is increasing daily. In the process of attaining green innovation, absolute dependence on the strength of the design team or the technical team is inadvisable. Instead, it is essential to effectively implement innovative

ideas and plans for producing the desired results. Also, teams must effectively cooperate with one another, so collaboration between individuals as well as between teams becomes crucial. Dredging of the immersed tube foundation trench and the floating channel is an essential prerequisite for the immersed tube floating installation. The SZL Project uses the immersed tube tunnel form to cross the Shenzhen waters. The dredging operation of the project will generate a large amount of dredged material, which will pose a major threat to the marine ecosystem and will be costly if all of it is dumped outside the sea. Therefore, effective measures are needed for the combined use of dredged soil. So the SZL Management Center in collaboration with various construction entities reported to the ecological environment department on the disposal of dredged material. By means of the themed demonstration, government coordination, etc., it decided to turn engineering waste into urban construction material source, and coordinated the dredged material disposal tasks of Guangzhou City, Zhongshan City, Shenzhen City, Dongguan City and (former) State Oceanic Administration South China Sea Branch. With the concerted efforts of the cities and SZL participants, dredged soil was treated and utilized, and dredging costs and consumption were reduced.

Not only can a purely constructive party possess synergistic ability, but everyone’s engineering construction process involves it as well. To tackle challenges that require teamwork, the participants need to give full play to the synergistic ability for effective communication and close cooperation, address problems at their roots, and achieve effective coordination throughout the entire process. This is the necessary condition and guarantee for accomplishing the ultimate objective.

4.1.2.3. Implementation ability. Green innovation in engineering will be achieved through a well-defined organizational management model. The ability of each team to accurately understand, act quickly, and protect the process is put to the test when putting the directives given by upper leadership at all levels and in all organizations into practice. This occurs when there is a deviation between the behavior and the goal or when the final product falls short of expectations. Similarly, in the handling of dredged soil at the SZL Project mentioned earlier, dozens of relevant teams and hundreds of personnel were involved. Each team

effectively and enthusiastically contributed to the process execution during the handling of dredged materials, resulting in the rapid processing of the materials. As well in the SZL Project in the process of intelligent manufacturing and intelligent pouring, the construction works, management personnel and many others strictly and effectively followed management procedures, thus ensuring the quality of construction and reducing energy consumption, cost waste and other aspects.

It is evident that the ability to implement is not only about strategy and decision-making; it spans the entire process from formulation to implementation. It involves everyone, not just the subject of the responsibility, but all participants, including the subject of the role and the object. Throughout the process of attaining the green innovation program or engineering and construction, each participant must efficiently and accurately execute the required program, which is the cornerstone to transforming the strategic planning of green innovation into results, and the core of the entire engineering and construction team to attain the objectives.

Through the introduction of the basic capacities and the case study, it is evident that the basic capacities give a basic guarantee for attaining the complex system of green innovation, and its path of action is shown in Fig. 1.

4.2. Composite capacities

Composite capacity is the ability of the owner of the engineering construction management to, on the premise of possessing basic capacities, fully integrate various capacities to respond to more rigid and changing situations or problems. It serves as the power and guarantee for attaining green innovation. With the effects of the composite capacity, green development and innovation can be realized fundamentally. This section also addresses the composite capacities required from both hard and soft system levels, i.e., the physical level and the management level.

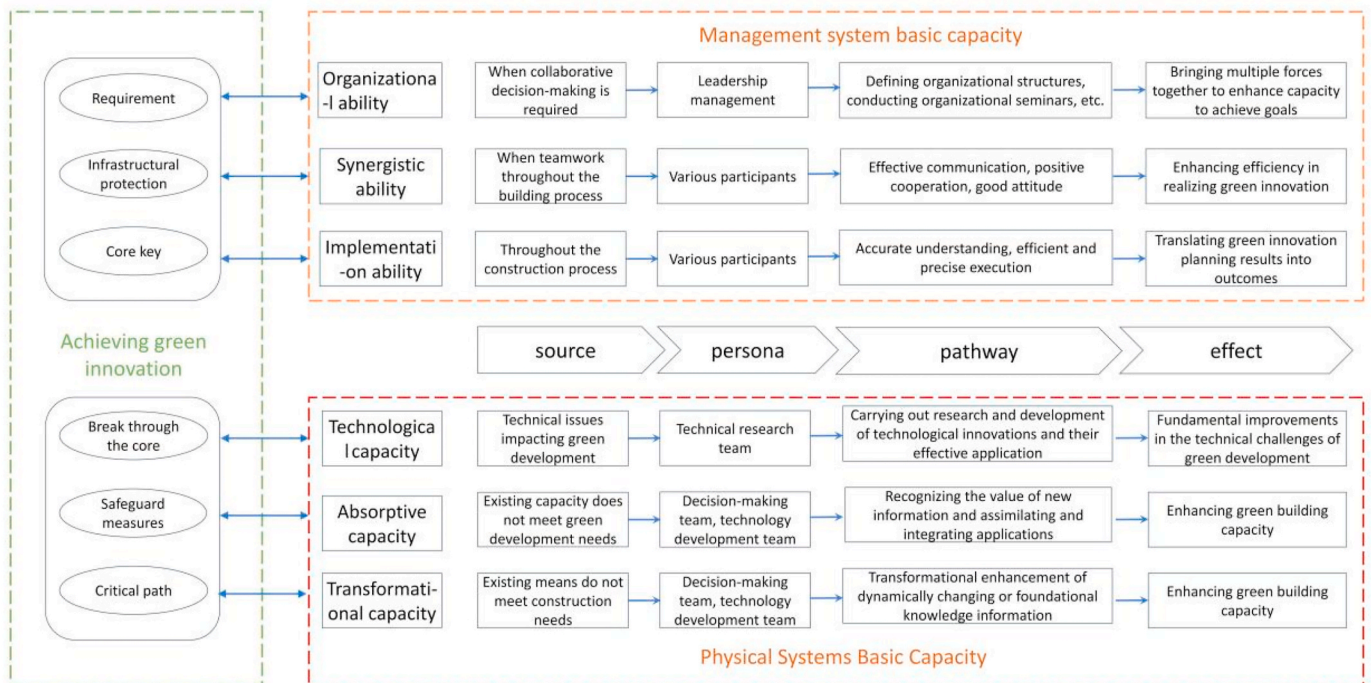


Fig. 1. Pathways for the role of basic capacities.

4.2.1. Physical-level composite capacities

4.2.1.1. Innovative capacity. Innovation is the most important word in green innovation. As the construction environment of engineering works is becoming much rigid, and the construction difficulty is increasing, existing technologies and techniques can no longer meet current construction requirements. Hence, to acknowledge the greening of rigid engineering construction, carrying out innovative development of all aspects of the construction process, technology and materials is a must. The SZL Project, for instance, has carried out green and innovative research in many aspects, including construction methods, engineering structures, installation and manufacturing, and research and development technologies. To achieve the intelligent manufacturing of immersed tube tunnels and steel box girders, the SZL Project has invented an intelligent line of manufacturing production, which improves manufacturing quality and efficiency, minimizes the instances of cutting, welding, and spraying loss, and therefore avoids repeated processing, rework and other ineffective losses. In terms of intelligent installation, the use of self-propelled ships integrating immersed tube transportation and installation reduces the risks involved in transportation and installation; the enhanced controllability of installation under adverse conditions also helps reduce the consumption of energy, materials and other additional resources due to the repeated trial-and-error process of installation. Besides, the SZL Project, as an offshore project, has long been exposed to sunshine, salt spray, wave impacts and other complex marine environments. As a result, a significant amount of material and human resources are required to implement quality and durability guarantee measures. In order to reduce the cost of maintenance and ensure the safety and service life, the SZL Project has invented anti-corrosion technology to enhance the durability of immersed tubes and bridges, reduce the use of consumables for repair and replacement in operation and maintenance, and mitigate the damage of corrosion to the marine environment. All these reflect the innovative capacity of SZL Project at the physical level.

To put it briefly, at the physical system level, the innovative capacity of engineering construction to acknowledge green innovation means that when existing processes and techniques cannot meet current construction requirements, or when they will produce many green development challenges, the construction research and development team, engineers and so on innovate and develop new construction process, equipment, means, technology, programs and others, resolve current bottlenecks, and acknowledge innovative development.

4.2.1.2. Digital-intelligence capacity. Digital-intelligence capacity has become a crucial component in the modern, fast advancement of science and technology, transforming and modernizing a wide range of industries. It is an integration in terms of physical technology, comprising a variety of digitally intelligent strategies and technologies, such as the IoT, Big Data, Cloud Computing and Blockchain. In engineering construction, energy consumption and cost waste can occur at various stages including initial program design, the supply chain during construction, the production of components, the construction process, and operation and maintenance after project completion. By giving play to the digital-intelligence capacity, project managers can combine and process a large number of complex information and solutions. For example, they may adopt digital tools to hastily and efficiently evaluate various options to help decision-makers choose the option, and so on. Apart from the intelligent methods the SZL Project employed in the fabrication, pouring and installation of the steel shells, at the beginning of the construction, the SZL Project utilized simulation techniques for vehicle operation mimicry to optimize the tunnel design scheme, enhance its lighting system, transform the lighting power supply system to be more energy-efficient, and set the high brightness coefficient of tunnel pavement materials and façade materials. These efforts help accomplish the current goals of improving conversion efficiency,

decreasing line loss, increasing light output from the efficient use of light sources, and greatly lowering the energy consumption of operating tunnel lighting systems.

Currently, engineering construction aims at attaining green innovation, and digital-intelligence capacity, the essential driving capacity, is a required hard power for construction managers. In the face of a large amount of complicated information and construction challenges, managers and decision-making teams, empowered by digital-intelligence capacity, can attain impactful, streamlined, systematic processing of information, enhance digital processing capacities, solve construction challenges, and attain the objective of green and high-quality development.

4.2.2. Management-level composite capacities

4.2.2.1. Mindfulness ability. Through the positive perception of new information, mindfulness is thought to be the foundation for fostering creativity and innovation. In this paper, the mindfulness ability to attain green innovation is a state of consciousness that safeguards the environment. When decision-makers face a large amount of rigid information and multiple goals, their ability to combine the objective of greenness with other objectives for holistic consideration reflects their comprehensive ability in the project. The management of the SZL has always kept the goal of green development and innovation in mind. In the process of interviewing the senior management of the SZL Project, it was made very clear by the chief engineers of the SZL that the project could not be built purely for financial gain, the construction of the SZL was always mindful of the requirements of the national development, and that the project's environmental benefits should come first. Engineering construction in the present social development process will comprise the largest energy consumption and will be most prone to create pollution in the industry. Taking on the mission of implementing the green highway demonstration project, the SZL Project is committed to integrating the "green" concept into the entire lifecycle of engineering construction, thus contributing to the national strategies of carbon peak and carbon neutrality.

It is evident that through the role of the ability of being mindful, decision-makers will put the goal of green development into the whole process of engineering and construction. They will act with awareness and determination to ensure environmental sustainability and innovation in the manufacturing process. This is the source and basis for green innovation, and will greatly curb the resistance of green innovation, and help to achieve the goal of green performance and green innovation.

4.2.2.2. Innovative ability. As was indicated in the previous section, creative research and development of construction technology and equipment reflects the hard system's capacity for innovation. However, in order to achieve green innovative development, hard system innovation only is insufficient. Relevant management programs, management tools and management systems also need to be enhanced, in a bid to ensure effective implementation of these processes and tools. The SZL Project also attaches significance to the innovative development of management to safeguard the engineering process. It innovatively developed and adopted an intelligent management system to attain the digitalized and information-based process of management, using the BIM platform to conduct all-round management of the installation, pouring, construction and other processes to minimize the cost of manpower control and to improve management accuracy.

The innovative ability in the soft system means that when managers encounter innovative technical solutions, they have to elevate their management innovation skills, update management solutions, acknowledge innovative development with the times, ensure the impact and application of green innovation, and maintain high levels and quality of construction.

It is clear from the summary of composite capacities that they are not

a single aspect of the engineering and construction process but rather a multifaceted process that involves all levels of synthesis in order to achieve the fundamental driving capacity of green innovation, as shown in Fig. 2.

4.3. Integration of capacities

The previous analysis summarizes the basic and composite capacities required for engineering construction managers in the process of achieving green innovation and development, and the relationship between green innovation and engineering construction. But in the process of attaining green innovation, these capacities are never a single existence, and only a basic or composite capacity is unable to achieve innovation. Instead, these capacities are interrelated and integrated, each of which in the different stages of the event, yielding distinct benefits for different challenges; and the role of all the capacities can truly acknowledge green innovation.

Fig. 3 takes the whole process of green innovation in the construction of immersed tubes for the SZL Project as an example, and summarizes how each capacity is demonstrated throughout the process.

5. Conclusion and discussion

In conclusion, given increasingly harsh conditions, the construction industry urgently needs green transformation and upgrades. Green innovation is also necessary for the entire engineering and construction life cycle. It is not a goal that can be attained by straightforward technical and technological innovation. Therefore, the research in this paper examines the construction process of complex engineering systems and splits it into two aspects: "hard system", i.e., the construction acknowledgement process of engineering entities, and "soft system", i.e., the acknowledgement process of project management during construction. The integration of realization process of green innovation in the SZL Project functional capacities is summarized through a thorough case study and an examination of its whole life cycle. Within these two systems, there are basic and composite capacities. Basic capacities comprise the organizational, implementation and synergistic abilities to attain the green innovation of the soft system, as well as the technological, transformational and absorptive capacities to attain the hard system; and composite capacities are split into the mindfulness ability and innovative ability to attain the green innovation of the soft system, and the digital-intelligence capacity and innovative capacity to attain the hard system. The basic capacities offer a reliable guarantee for the achievement of the green innovation process, while the composite capacities offer the powerful driving force for the acknowledgement of

green innovation, and in the fusion of composite capacities and complex systems, the high-quality development of green innovation of the project can be realized.

Theoretical contribution: In existing studies, the pursuit of green performance in the construction industry is more focused on quantitative methods and models. Few studies have addressed the capacity and realization path of the main body "managers" in realizing the goal, and there lacks systematic description of this aspect. Therefore, this paper introduces the concept of "capacity" from the perspective of complex engineering systems to analyze the internal driving force of green innovation, in a bid to explore the figurative expression of the form of correlation within major engineering systems. This approach aims to provide insights into the interactions and linkages between the elements within a megaproject, revealing the internal dynamics and mechanisms that facilitate green innovation. Since these correlations and influences are not easily measurable, visually perceptible or clearly definable, the concept of "capacity" helps us understand the micro-behavioral mechanisms of engineering organizations in promoting green innovation, and offers crucial theoretical support for achieving green innovation.

Relevance: This paper takes the case of SZL Project as a starting point to probe into the key new quality productivity required for achieving green innovation, and offers project managers more precise and efficient management strategies. By introducing systematic key new quality productivity, project managers can better steer the project's development to meet green innovation requirements and achieve both economic and social benefits. This provides strong support and guidance for accomplishing green innovation in megaprojects.

Limitations: The research in this paper has certain shortcomings that should be addressed in future work. On the one hand, the SZL Project selected in this paper has not been in full operation, so information on green innovation development during its post-completion operation remains incomplete. On the other hand, while our study of the SZL Project is thorough, the limited number of cases studied poses challenges for generalizing our findings. Therefore, we propose that future studies integrate case studies and large model studies to explore the determinants of acknowledging green innovation in depth and extensively, with a view to better shouldering project managers in green innovation management.

CRedit authorship contribution statement

Sha Tao: Writing – original draft, Investigation, Funding acquisition.
Xinyi Pang: Writing – original draft, Investigation.
Yumin Qiu: Writing – review & editing, Methodology, Data curation, Conceptualization.
Qingshuang Xu: Investigation.
Peng Xue: Writing – original draft.

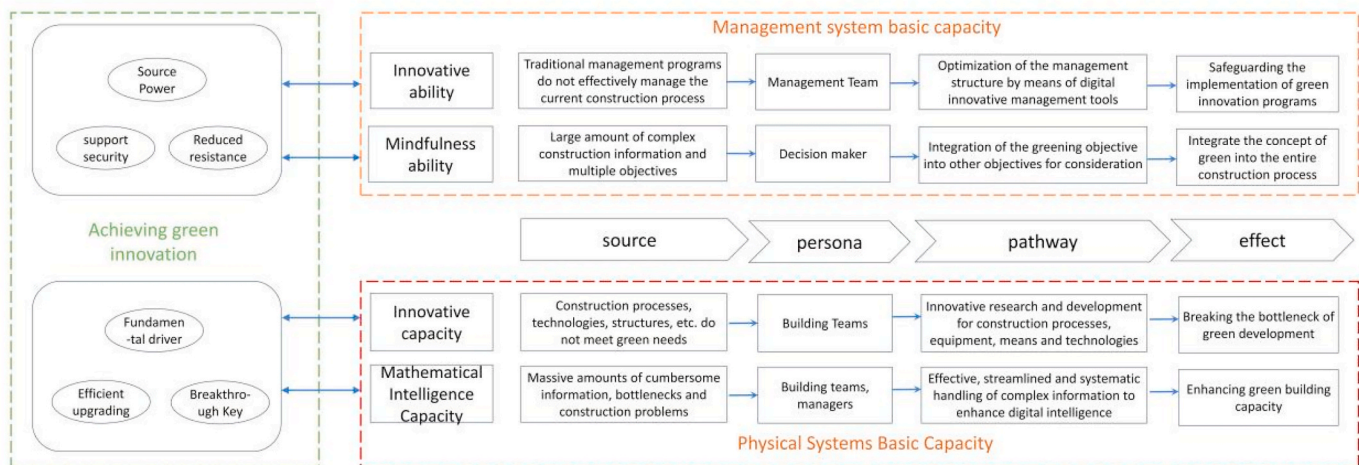


Fig. 2. Pathways for the role of composite capacities.

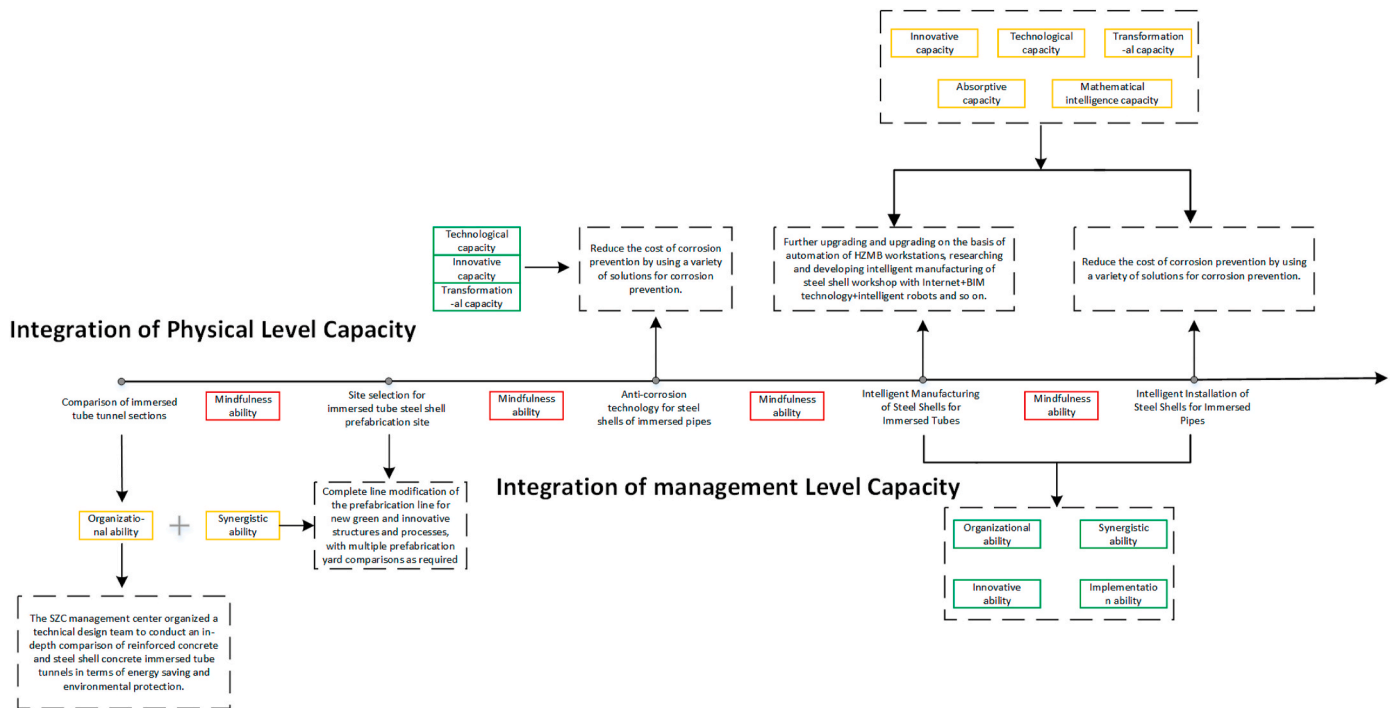


Fig. 3. Capacity integration of the whole process of immersed tube green innovation in the SZL Project.

Declaration of competing interest

All authors disclosed no relevant relationships.

Data availability

Data will be made available on request.

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Appendix

In conducting semi-structured interviews, the following main questions were supplemented with appropriate follow-up questions based on participants' responses.

- Why do you think green innovative development is necessary? What is the green innovative development of SZL?
- What are the main factors included in realizing the green development of the project?
- What preparations have been made to realize the green innovative development of SZL?
- What are the main processes and aspects of the construction of the project covered by these preparations?
- What kind of problems will be encountered in the process of realizing green and innovative development? How to deal with them?
- What do you think is the most important when solving problems?

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