HOW COLLABORATIVE INNOVATION SYSTEM IN MEGAPROJECTS EVOLVES? AN EMPIRICAL STUDY OF THE HONG KONG-ZHUHAI-MACAO BRIDGE PROJECT

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Abstract: Infrastructure megaprojects (shortly megaprojects), bringing together heterogeneous stakeholders, e.g. government, owners, and contractors, are an ideal context for developing a collaborative innovation system. This paper presents the evolution of the collaborative innovation system from the perspective of the transformation of stakeholders’ salience and functional roles. We empirically grounded our study on the Hong Kong-Zhuhai-Macau Bridge (HZMB) megaproject in China, analysed with the stakeholder, innovation, and collaborative innovation system theoretical lens. The case shows that the collaborative innovation system can be divided into four stages, namely the birth stage, development stage, mature stage, and re-innovation stage. Stakeholders’ salience usually remains unchanged with exception of engineering consulting firms, and stakeholders’ functional roles evolve in eight different directions. The study provides practical guidance on dealing with collaborative innovation in infrastructure megaprojects.

Keywords: Collaborative innovation; Functional roles; Megaprojects; Salience; Stakeholder.
1. Introduction

Infrastructure megaprojects (from now on megaprojects) refer to uniquely large, complex projects involving exceptionally large budgets, long implementation cycles, multiple public and private stakeholders, and an enormous impact on the regional economy and natural environment [10]. Megaprojects are often criticised for unsatisfactory project performance, poor innovation and digitalisation, low customer satisfaction, etc. [21]. Innovation is regarded as an effective method to address those issues and improve economic, social and environmental sustainability [19].

Given the complexity of megaprojects and the involvement of numerous stakeholders regarding infrastructure project construction, innovations are often collaborative [20]. Innovation in megaprojects includes multidisciplinary activities requiring firms/organisations combining knowledge and experience in different fields [23]. Traditional innovation paradigms (e.g., a contractor implements all innovations required) are, therefore, challenging in the context of megaprojects. Thus, promoting collaborative innovation is increasingly imperative in megaprojects. Collaborative innovation fosters stakeholders to collaborate to achieve the infrastructure project by sharing information and knowledge [24]. With the development of collaborative innovation, a collaborative innovation system that encompasses a set of interconnected and interdependent networked actors/organisations focused on joint value co-creation and capture, gradually forms and evolves [2].

A plethora of stakeholders, including the traditional stakeholders in the construction industry (e.g. contractors and designers) along with governments, universities, safety authorities, etc. are involved in the collaborative innovation system to ensure the successful delivery of infrastructure megaprojects [9]. These stakeholders possess different salience which refers to the attributes (i.e. power, legitimacy, and urgency) they possess [27] and play diverse functional roles across different stages of megaprojects.

The unit of analysis in this study is, therefore, the “transformation of stakeholders’ salience and functional roles during the evolution of the collaborative innovation system”. The level of analysis is the megaproject level, i.e. we will study the evolution of the collaborative innovation system in the context of a specific megaproject. Thus, the key novelty of this study is analysing the evolution of the collaborative innovation system in megaprojects from the transformation of stakeholders’ salience and functional roles perspectives.

2. Literature Review

2.1 Megaprojects Stakeholders

Stakeholders management is a crucial part of innovation management [31] and a precondition for megaproject success. Stakeholders have different motivations, interests, goals, and expectations, thus, when they enter the project, they impact project implementation and delivery [15]. Symmetrically, the planning and delivery of
megaprojects affect stakeholders’ reputation and development. Therefore, the term “stakeholders”, in this study, refers to those organisations or individuals that have an influence or are influenced during the planning or delivery of megaprojects.

Existing project stakeholder literature provides useful frameworks for classifying and categorising stakeholders by investigating their motivations, attributes, or even behaviours [25, 26]. Paper [25] introduced three attributes, including power, legitimacy, and urgency, to classify stakeholders and establish their salience. Following paper [25], we classify megaproject’s stakeholders into definitive, expectant, and latent.

Functional roles describe the effects which stakeholders have on achieving specific goals [5], for example, providing essential resources to design a unique undersea bridge. Stakeholders possessing different salience in a network play different functional roles [28]. According to paper [22], we cluster stakeholders’ functional roles into three types, including dominator, participant, and opportunist.

2.2 Innovation in Megaprojects

Innovation in megaprojects can be explained as a “new product, process, or service that has a step change and creates value, e.g. financial value, environmental value, societal value, job creation etc.” [32]. Paper [6] defined innovation in megaprojects as “novel or significantly improved ideas, products, processes, technologies, tools, and organisational methods at the project-level and firm-level, creating value for firms and megaprojects” (p. 2). Based on reviewing existing literature, innovation in this study is defined as a new or significantly improved technology, product (goods or service), process, technical, or organisational method creating value for firms and megaprojects. In this context, many megaprojects are innovations themselves, such as longer bridges than built before, deeper and/or longer tunnels, new nuclear reactors etc.

2.3 Collaborative Innovation System

The expression “collaborative innovation system” refers to the collaborative networks and interaction relationships among various stakeholders towards innovation and value creation [3]. A collaborative innovation system includes many interconnected and interdependent stakeholders, such as the government, local communities, non-government organisations, etc [1]. A collaborative innovation system is usually led by a platform leader who sets the rules and goals, provides a common platform, and is responsible for the system’s healthy [11]. A collaborative innovation system has a lifecycle that follows the co-evolution process [11]. Paper [5] summarised the evolutionary stages of the innovation ecosystem in megaprojects, including the birth, development, mature, and renewal/death stage. The classification provides a valuable reference to the formation and development of the collaborative innovation system in megaprojects.
3. Research Method

3.1 HZMB Megaproject

The HZMB megaproject is the first large sea crossing megaproject being built jointly by three local governments of China, including the Hong Kong Special Administrative Region (HKSAR), the Macau Special Administrative Region (MSAR), and Zhuhai city of Guangdong Province in China Mainland. The HZMB megaproject started in August 2003 and completed the construction work in February 2018, when delivered to HZMBA (the client) for commission and operation. During this period, four administrative organizations were established: the HZMB Pre-coordinating Group (HZMB PCG), HZMB Task Group (HZMB TG), HZMB Joint Working Committee (HZMB JWC), and HZMBA. HZMB PCG was established by three local governments in August 2003 to undertake preliminary research and was the sponsor. HZMB TG which was led by National Development and Reform Commission (NDRC) and established in December 2006, worked as a sponsor to coordinate disputes and deal with resolutions. In May 2010, the three local governments established HZMB JWC which served as a new sponsor to take the following work of HZMB PCG. The HZMBA was officially established as a client in July 2010 and was responsible for the construction, operation, and maintenance work.

The innovation in the HZMB megaproject is a decentralised project which has created new software, new equipment, new products, and new patents. Innovation is also part of the project's strategic objectives. In the project initiation stage, more than 80 monographic studies, especially those connected with one country and three technical standards were prepared by consulting firms and research institutes. In the project implementation stage, three levels of innovative research were carried out, including the “HZMB construction cluster key technology research and demonstration project”, and monographic studies organized by client and contractors respectively. Hundreds of construction firms and research units were involved in the innovation process and were organized by different forms of collaboration, such as consortium (e.g., preliminary design consortium, design and construction consulting consortium), long-term partnership and cooperation.

3.2 Research Design

3.2.1 Data Collection

To identify innovations and stakeholders involved in the HZMB megaproject, we accurately reviewed 326 archival documents and made a first-round of 8 long semi-structured interviews. The triangulation achieved by using multiple data sources (data triangulation) assured the validity and reliability of research findings.

From November 2019 to March 2020, we conducted the first-round of 8 semi-structured interviews to promote our understanding of archival documents and collect more relevant information. Each interview lasted about 60-90 minutes and was recorded (under the permission of interviewees) and transcribed. Each interview aimed to investigate
innovations implemented, organisations/firms/individuals involved in different innovations, the process of innovations, and their functional roles/responsibilities.

3.2.2 Data Coding and Analysis

First, the collected data were coded by a hybrid approach including both deductive (formation of themes stemming from literature) and inductive coding (formation of themes from the data itself). The data were coded through Nvivo 12.

Second, the questionnaire survey results were calculated and selected. We selected the key stakeholders which were chosen by 34 experts from the HZMB megaproject according to the criteria of the “50%” frequency [22].

Third, we adopted the technology roadmap method [33] to identify the four stages of the collaborative innovations system in the HZMB megaproject.

3.2.3 Validation

From May to July 2021, experts who did not attend the first-round semi-structured interviews were contacted to take a new round of interviews to assess our findings and confirm the achievement of theoretical saturation.

4. Findings

4.1 The Roadmap of the Collaborative Innovation System in the HZMB Megaproject

During 2003 and 2020, the collaborative innovation system of the HZMB megaproject went through four stages, as shown in Figure 1.

During the birth stage, the government, HZMB PCG, experts, and intermediaries (e.g. Engineering consulting firms (ECF), Research institutes and universities (RIU)) collaborated to define project goals and schemes, and participate in pre-innovation activities (e.g. determining bridge location and route, proposing management philosophy and framework). In the development stage, the government, HZMB PCG, HZMB TG, designers, experts, and intermediaries were involved in the collaborative innovation system. Many innovations had been made by stakeholders’ joint efforts, such as introducing the whole process engineering consulting service, adjusting the collaboration mode among China Mainland and international firms to meet the requirements of China Mainland’s construction laws and regulations, etc. During the mature stage, HZMBA, contractors, designers, suppliers/manufacturers, intermediaries, etc. were involved in the system to achieve the construction project goals. They collaborated to achieve the construction goals by making innovations, including a few world-class innovations, e.g., the rapid formation of an artificial island, floating transportation and installation of an immersed tube, etc. With the project completed and commissioning started in October 2018, the formal relationships among stakeholders began to break up and a few stakeholders worked together in other megaprojects (e.g. CCCC Co. Ltd., and Tunnel Engineering Consultants form a consortium to construct the Dalian Bay Undersea Tunnel).
Figure 1. The roadmap of the collaborative innovation system in the HZMB megaproject
4.2 Key Stakeholder Identification

Table 1 shows key stakeholders selected by experts for each stage. It is clear that not only traditional construction project stakeholders (e.g. designers, contractors) but also stakeholders from other industries (e.g. Meteorological and IT service providers (MITSP)) are involved and work as key stakeholders in promoting innovations in the HZMB megaproject.

**Table 1. Key stakeholders involved in each stage in the HZMB megaproject**

<table>
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<tr>
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<th>Birth stage</th>
<th>Development stage</th>
<th>Mature stage</th>
<th>Re-innovation stage</th>
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HZMB PCG, HZMB JWC, HZMB TG, or HZMBA serve as key stakeholders in the collaborative innovation system’s lifecycle successively to either deal with institutional complexity or establish a project management framework and concepts. Governments are also key stakeholders in the collaborative innovation system’s lifecycle as they made decisions to build the HZMB megaproject, provided funds and resources, convened experts to review different proposals, etc. EG and ECF collaborate with others to make innovative solutions (e.g. the final joint of immersed tubes) in the system’s lifecycle and are significant innovation contributors and value creators. RIU enter the system in the development stage and make great contributions to research and development, especially the “HZMB construction cluster key technology research and demonstration project”. Designers, contractors, suppliers/manufacturers, PSC, and MITSP are the key stakeholders that are involved in the system just for one or two stages to implement the innovations and deliver the megaproject.
4.3 Stakeholder’s Salience and Functional Role Analysis

Table 2 demonstrates the transformation of stakeholders’ salience and functional roles during the evolution of the collaborative innovation system. The number of definitive stakeholders increases gradually in the first three stages. Also, stakeholders’ salience and functional roles overlap to some extent and this can be explained by the fact that “powerful stakeholders are supposed to take the leaders role to address the issues” and “powerful stakeholders possess critical resources and are more capable of obtaining support from others” [18]. Of key stakeholders, the government remains a definitive stakeholder.

Table 2. Transformation of stakeholders’ salience and functional roles

| Stage        | Definitive | Expectant | Late
|--------------|------------|-----------|------
| Birth        | Government | HZMB JWC  | HZMB TG | HZMB A | EC F | Contractor | Design | HZMB PCG | EG | ECF | Suppliers | MITS | RIU |
| Development  | %          | #         | %        | #      | %    | #       |       | #        | %  | %   | %         |      |     |
| Mature       | *          | %         | %        | #      | #    | %       | %     | %        | %  | %   | %         |      |     |
| Re-innovation| *          | *         | #        | #      | #    | %       |       | %        | %  | %   | %         |      |     |

# represents dominator, % represents participant, * represents opportunist

The HZMB PCG, HZMB TG, and HZMB JWC (also known as sponsors) keep their salience unchanged as they can exert penalties to force participating units to conduct innovations when existing technologies cannot solve the construction problems. As sponsors, they influence the innovation decision-making and implementation as they possess power and legitimacy to combine information and resource [14]. HZMBA, as a client, has the power and legitimacy to integrate firms and resources to construct, manage, and operate the HZMB megaproject. Designers and contractors gain power and legitimacy to conduct innovation activities, thus they are definitive stakeholders.

EG is one of the expectant stakeholders invited by HZMB PCG in the birth stage and maintains this salience across the system’s lifecycle. Indeed, EG is an “important contributor to innovation with the power to propose or determine innovation schemes and huge impacts on the innovations’ implementation” (Interviewee 09), whereas they gain no legitimacy and get less attention in innovation management.

The stakeholders involved in the collaborative innovation system can be divided into eight types based on the functional role transformation they experience. The first category of stakeholders, the government and sponsors (composed of HZMB PCG, HZMB JWC, and HZMB TG), experience a transformation from dominator to participant and opportunist. The second category of stakeholders, including ECF only, changes from participant and dominator to opportunist. The third category of stakeholders consists of the client (HZMBA). The client plays a dominating role and leads the collaborative...
innovation system in the mature and re-innovation stage. The fourth category of stakeholders includes the EG which transforms from opportunist to participant and then to opportunist again. The fifth category of stakeholders includes the suppliers/manufacturers and MITSP, playing an opportunist role in the development or mature stage. The sixth category of stakeholders includes contractors and designers, which mainly play the dominant role in the development/mature stage. The seventh category of stakeholders includes RIU which change from dominator in the development stage to participants then. The eighth category of stakeholders includes PSC which play the participant role in the mature stage.

5. Discussion and Conclusion

Given the complexity and involvement of numerous stakeholders in megaprojects, collaborative innovation is an imperative pathway toward achieving project goals. This study draws on the literature on stakeholders, innovation, and the collaborative innovation system to analyse the transformation of stakeholders’ salience and functional roles during the evolution of the collaborative innovation system. Based on the empirical research of the HZMB megaproject, this study has shown that the collaborative innovation system can be divided into four stages: the birth stage, development stage, mature stage, and re-innovation stage. The second finding is that stakeholders’ salience usually remains unchanged, the notable exception being ECF. These findings have significant implications for the understanding of how to manage stakeholders’ relationships based on their salience and functional roles in different stages of the collaborative innovation system in megaprojects. It also provides insights for analysing the evolution of the megaproject innovation system from the perspectives of stakeholders’ interactions.

5.1 Transformation of Stakeholders’ Salience

Stakeholders’ salience transforms with the evolution of the collaborative innovation system and the result validates studies in infrastructure projects [18] which showed how the powers of stakeholders (e.g. governments) decreased with the project implementation.

Of all key stakeholders, we found that governments are definitive stakeholders in the collaborative innovation system’s lifecycle. This finding is contrary to the notion that internal stakeholders have more salience to affect project objectives, including project innovations [7]. Many megaprojects are initiated by governments in China, therefore the government has the largest power to decide whether to provide resources and supports to innovations or not; the maximum legitimacy to enforce innovation-related policies.

The contractors and designers work as definitive stakeholders when they are involved in the collaborative innovation system. The reason is that a large-section construction contract and the general contracting mode of systematic integration are promoted in the HZMB megaproject, thus, the contractors and designers are empowered by the client to transform project goals into practice by developing novel construction technologies and techniques.
ECF changes from definitive stakeholders to expectant stakeholders when the collaborative innovation system changes to the re-innovation stage. ECF have advanced knowledge and valuable experience in construction methods, construction processes, construction technologies, and construction techniques [12], thus, they are empowered by the client or government to propose and review innovative solutions during the early stages of project conceptualization.

5.2 Transformation of Stakeholders’ Functional Roles

Stakeholders’ functional roles transform in different directions, along with the evolution of the collaborative innovation system. This is a consequence of the fact that different stakeholders possess different core resources to implement innovations and are good at different disciplines [19].

Differently from [32], we found that government/sponsors’ functional roles change from dominator to participant and opportunist. This is because megaprojects are commissioned (at least partially) by the governments and are politically sensitive [13].

Consistently to [8], the client is the leader of innovation management and is also responsible for organizing and managing the collaborative innovation system. As the leader in the collaborative innovation system, they are at the intersection of construction knowledge and information and at the centre of coordinating collaboration relationships among stakeholders [29].

ECF’s functional role changes from participant and dominator to opportunist, which confirms the contributing role of ECF as internal stakeholders who have both formal and informal collaboration relationships with infrastructure projects [16]. Indeed, ECF are invited by the client or sponsor to advise on pre-innovations in the birth stage and work as a dominator to propose or even review innovative schemes in the development and mature stage [4], and gradually lose its core position when the system enters into re-innovation stage [29].

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