Investigating the Future Architecture of Construction Projects

by

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Submitted to the System Design and Management Program
In Partial Fulfillment of the Requirement for the Degree of

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ABSTRACT

Japanese construction industry is currently struggling with technology development due to the resisting forces against introducing and developing new technologies into the construction sites. In order to analyze the current situation and develop the potential preferred architecture, ARIES, a system architecting framework is applied to the construction project team as the targeted enterprise in this research.

First, the current architecture of the enterprise is analyzed from ten elements including landscape and stakeholder. While many ecosystem factors are driving technology development, it was made clear that the weak relationship of the construction project team with the leading-edge technology suppliers led to the team's lack of knowledge and information about new technologies, resulting in generating the resisting forces against introducing new technologies. After analyzing the current situation, the envisioned future was created based on the capability of both the company and the construction project team.

Second, in order to generate novel ideas about the alternative architectures, case studies of different industries were performed, where the importance of taking into account the supplier's needs and communicating continually with the workers on site was identified. After several alternative architectures were generated and evaluated by an unweighted decision matrix, the combined architecture consisting of the connecting platform and the on-site events was selected as the future architecture. Finally, based on the risk assessment, the detailed architecture and the implementation plan were developed, which have an emphasis on interaction between the connecting platform and the on-site events.

ARIES framework was applied to this research effectively in that both the current and future architecture of the enterprise were analyzed, evaluated, and validated from a holistic point of view. In addition, this research gave a valuable insight that interaction among multiple sub-systems is important for the entire system to work successfully. Considering that the research was performed by a single person, the author, the future work would be discussing the proposed architecture with other multiple members to improve it.

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ARIES - Architecting Innovative Enterprise Strategy

CIM – Construction Information Modeling

ICT – Information and Communication Technology

IoT – Internet of Things

JSCE – Japan Society of Civil Engineer

MILT - Ministry of Land, Infrastructure and Transport and Tourism

TRL – Technology Readiness Levels

CONOPS – Concept of Operations

Chapter 1: Introduction and Overview

Technology development has accelerated year by year. In addition to the speed, the complexity and diversity of industries and societies allow technologies to spread out across domains as well as countries, which indicates that the industries need to reach out and leverage technologies across disciplines in order to solve the complex issues that they currently have. This rapid and expansive change drives industries and companies to transform themselves so that they can catch up with the change and get ahead of the competition. Considering that technology makes a significant contribution only after it is leveraged adequately, what is important is how industries and companies acknowledge the value of the emerging technologies and leverage them appropriately. New technologies do not always contribute to the growth of the industries because there are not only the driving forces for change but also the resisting forces against change. It is crucial to identify these forces correctly and manage them all the way to the completion of transformation. When managing the forces, it is important to take into account both technical and social aspects in the industries.

This chapter introduces the research described in this thesis, including problem definition, research objectives, approach, and research overview.

1.1. Problem Definition

Construction industry in Japan has grown by leveraging technologies developed inside the industry for a long time. Recently, due to aging of workforce, the industry is trying to transform itself in order to enhance productivity by utilizing cutting-edge technologies developed in different disciplines such as IT, IoT, AI, robotics, and automation as the government promotes. However, the transformation has not worked well. While there are some driving forces for transformation as mentioned above, the resisting forces against change prevent quick and smooth transformation. The restraining forces consist of not only technical aspects such as current technology development

systems and the skills of workers, but also social aspects such as organizational structures and working cultures which have been established and embedded for a long time. Especially, these forces against change can be seen in construction project sites which are located far away from headquarters in terms of value and culture, as well as physical distance. Transforming construction projects is critical in order to transform the entire construction industry successfully.

1.2. Research Objective

The primary research objective is to investigate the application of a system architecting framework to construction projects in Japan. ARIES, Architecting Innovative Enterprise Strategy, is a system architecting framework which guides the architecting teams in analyzing current architecture of the enterprise and its environment holistically, and in generating and evaluating future architecture. Through the application of the framework, the research investigates how to mitigate the drivers against change and facilitate driving forces by changing the architecture of construction projects, which eventually contributes to transformation of the construction industry.

The research questions are as follows,

- What are the root causes of the current situation of technology development in Japanese construction projects?
- What is the potential preferred architecture of construction projects to drive technology development?

1.3. Approach and Research Overview

This thesis consists of the following structure, reflecting the approach of the research. The research method is described in Section 2.5.

1. **Introduction and Overview**: The context and the objectives of the research on the investigation of the future architecture in construction projects are mentioned. Also, the approach and research overview are described.

2. **Literature Review:** The literature is widely reviewed to identify the characteristics of enterprise transformation and how to design future architecture. In addition, literature related to analogical thinking, organization analysis, and change management is reviewed to complement a system architecting framework. This literature review is a guide to identify the research method of the thesis.

3. **Application of ARIES Framework I:** This chapter describes the application of first half of ARIES framework, a system architecting framework. It consists of enterprise landscape, stakeholder analysis, current architecture, and holistic vision of the future.

4. **Case Study:** Case studies are performed in order to guide generating alternative architectures, the following process of the ARIES framework. Three cases in the logistics industry are selected due to the similarity to the construction industry. Additionally, literature review of an innovation platform is performed.

5. **Application of ARIES Framework II**: This chapter describes the application of the latter half of ARIES framework which consists of generating alterative architecture, deciding on the future architecture, and implementation plan.

6. **Conclusion:** The final chapter describes conclusion, summarizes the findings in previous chapters, and future works.

Chapter 2: Literature Review about Enterprise Transformation

Before focusing on the construction industry, literature review was performed to identify the appropriate method for the research. In this chapter, the concept of enterprise transformation and the system architecting frameworks are described at the beginning. Additionally, literature of analogical thinking, organizational analysis, and change management is reviewed to enrich the framework. At the end, the appropriate method for the research is described.

2.1. Enterprise Transformation

While there are many kinds of enterprises such as corporations, government agencies, and universities, they have some common characteristics [1]: an enterprise is composed of people who generate value for others, an enterprise is a whole system that has a purpose, a "reason for being", an enterprise achieves the benefits from being a part of its larger system. Enterprise needs to transform itself depending on the change of the surrounding environment since it is strongly interrelated with its surrounding. The more disruptive and rapid the change is, the more effort for transformation is required. Although enterprises realize the necessity of transformation, many failures of transformation are found here and there. The characteristics of the failures are as follows [1]: overly focusing on organization, forgetting stakeholders, thinking it is all about technology, silo effects, thinking that information technology will fix everything. The commonalities of the characteristics are overly focusing on a single specific aspect and overlooking the surrounding environment. Therefore, the holistic analysis is crucial in order to transform the enterprise successfully.

William Rouse has written many articles about enterprise transformation. He regards the work of enterprise as a system with challenges to be addressed rather than routine operations [2]. As Figure 1 shows, these challenges are related with each other and should be addressed to achieve growth which is regarded as the goal of the enterprise. While a particular challenge may be solved

by process improvements or other incremental changes, he points out that addressing these challenges may involve enterprise transformation in some cases. Rouse also refers to the points of attention about approaches to transformation. Although installing information technology is deployed as a solution to the challenges, he points out that it is only a beginning. Rather than that, addressing the people and organizational issues is often more troubling and essential to achieve successful transformation. For example, understanding work process, both as they are and should be, training and aiding of personnel, and alignment of incentives and rewards with new process are important. Therefore, it is important to consider not only technical aspects but also social and cultural aspects.

Figure 1: Relationships among challenges [2]

Although there are many kinds of frameworks for enterprise transformation, ARIES framework provides a holistic approach which guides the selection of preferred architecture instead of the development of a detailed architecture for implementation. As Figure 2 and Figure 3 shows, ARIES framework provides the elements model which has ten lenses for looking at the enterprise and the architecting process model with eight activities. The ten lenses enable viewing the enterprise holistically, and the architecting process guides selection of right architecture step by step.

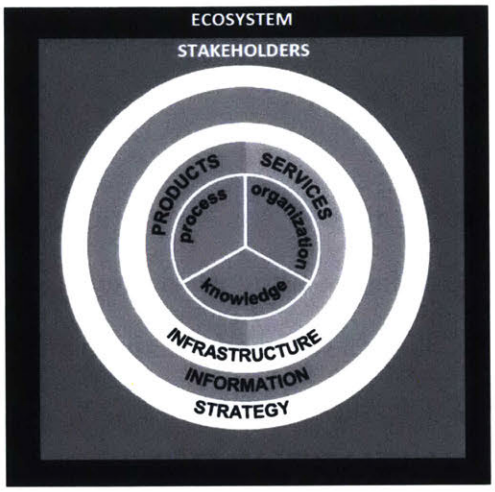


Figure 2: Ten elements for viewing the enterprise of ARIES framework [1]

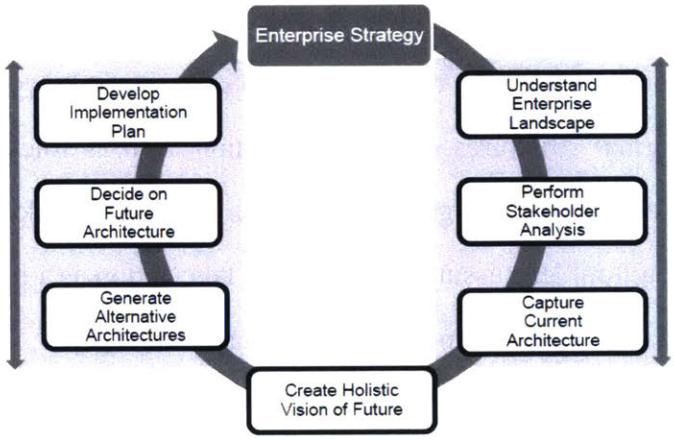


Figure 3: Process of ARIES framework [1]

2.2. Analogical Thinking

Among the activities in the architecting process shown in Figure 3, generating alternative architectures is important but difficult to perform successfully. Although there are some techniques which help generate novel and innovative concepts, it relies heavily on the ability and creativity of people working on the activity. Also, people working for the enterprise tend to be trapped by stereotypical views of the enterprise, which may make it more difficult to come up with novel ideas. In this context, analogical thinking is one of the most effective ways to generate innovative ideas [3]. It enables one to come up with new ideas by transferring information from well-known

domains and utilizing them in a novel domain. This indicates that the issues in a construction industry can be solved by the ideas derived from different industries.

2.3. Organizational Analysis

Since organization is nothing more than one of the aspects to view an enterprise, overly focusing on organization may lead to failure of transformation. However, analyzing organization is crucial when analyzing enterprise from a social perspective. Due to its complexity and diversity, many frameworks and methods for viewing organizations are proposed. Among them, a framework called "The Three Lenses" helps to gain new insights and understanding of organizational dynamics and human behavior within organizations by viewing an organization from three perspectives, the strategic design lens, political lens, and cultural lens [4]. The strategic lens views an organization as a machine that has been designed to achieve goals by carrying out tasks, and focuses on formal structures of an organization such as roles, responsibilities, and hierarchy. The political lens views an organization which consists of stakeholders with different goals and interests. The cultural lens assumes that people take action as a function of the meaning they assign to situations, and focuses on norms, values, and beliefs [5].

Among the three lenses, Thomas Malone focuses on the strategic design lens and regards an organization as supermind, a group of individuals acting together in ways that seem intelligent by his definition [6]. He mentions that the organization structures have been changed recently from centralized structure to decentralized structure due to lower communication costs achieved by new technologies, which enables people have enough information to make more decisions for themselves. Also, he points out that the change is driven by business benefits of more people having more freedom and flexibility. As this example illustrates, new technologies have potential to change organization structures.

2.4. Change Management

Enterprise transformation tends not to be completed immediately but takes time. Going through appropriate steps and processes is key to successful transformation. Lewin proposes a simple change management model which consists of three stages, Unfreezing, Change, and Freezing [7]. The purpose of the unfreezing stage is to prepare the enterprise to accept that change is necessary. It involves breaking down the existing quo before building up a new way of operating. The second stage is change or transition where people begin to resolve the uncertainty and look for new ways to do things. People need to understand how it will benefit them as well as the change is necessary and will benefit company. The last stage is refreezing where the enterprise establishes stability once the changes have been made, and the changes are accepted and become the new norm.

Among these three stages, the unfreezing stage is important in that it is necessary to make people in the enterprise get motivated for the transformation. Lewin also established the method for developing a clear awareness of both the driving forces for changes and the resisting forces against changes, called Force Field Analysis [8]. It is easy to assume that the transformation will not be successful if the forces against change are more powerful than the driving forces for change. Therefore, understanding and managing these two types of forces is crucial for enterprise transformation. Many researchers have applied force field analysis to the real world projects and found insights. First of all, Edgar H. Schein said "... just adding a driving force toward change often produce an immediate counterforce to maintain the equilibrium. This observation led to the important insight that the equilibrium could more easily be moved if one could remove the resisting forces, since there were usually already driving forces in the system" [9]. This indicates that it is important to consider how the future architecture and its process affect the balance between driving forces and resisting forces. Also, Daniel Levi classified the driving forces and the resisting forces in terms of types, location, and controllability in his research on technological innovation in organizations [8]. In terms of types, the forces are divided into four groups: Technological forces

(e.g. existing and new technologies), Financial forces (e.g. costs to adopt innovation and strategic advantage), Organizational forces (e.g. organizational structures, processes, and culture), and Individual and social forces (e.g. capabilities, concerns, and perceived benefits). Regarding location, the forces are divided into two groups based on whether the force is internal or external to the organization.

In addition to Lewin, John Kotter points out managers should realize that transformation is a process which takes time rather than an event and shortcut never works [10]. He has established eight stages of successful large-scale change: 1. Increase urgency, 2. Build the guiding team, 3. Get the vision right, 4. Communicate for buy-in, 5. Empower action, 6. Create short term wins, 7. Don't let up, 8. Make change stick [11]. The commonality of these eight stages is to place great importance on involving many people in the transformation and maintaining their incentives until the transformation is completed. He says that it is important to keep sharing appropriate vision and information with people involved.

2.5. Research Method

The method for this research was finalized based on the literature review described above. The research objective is to investigate the application of a system architecting framework to construction projects in Japan. ARIES framework was adopted as a basic framework since it is applicable to any kinds of enterprises and enables one to view an enterprise holistically. In addition to this framework, case studies are performed for generating alternative architectures as Figure 4 shows. Based on analogical thinking, the case studies are chosen in different industries instead of the construction industry in order to break down the stereotypes in the industry and generate innovative ideas. For example, the logistics industry is selected due to the similarity to the construction industry. In the analysis of case studies, what is focused is how the transformation affected the balance between the driving and resisting forces. The design of case studies and the detailed analysis method are described in chapter 4.

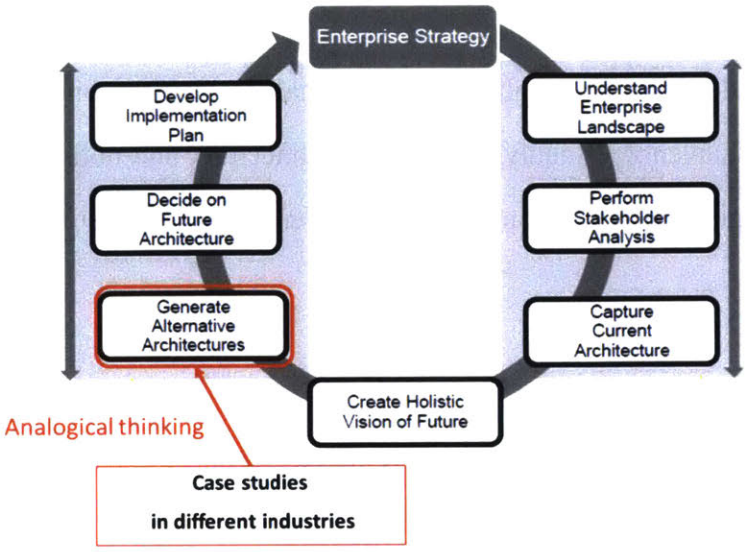


Figure 4: Framework for the research (adapted from [1])

Chapter 3: Application of ARIES Framework I

This chapter describes the application of first half of ARIES framework which consists of enterprise landscape, stakeholder analysis, current architecture, and holistic vision of the future. Before applying the framework, the constituents in the enterprise ecosystem, scope, and boundary are described.

3.1. Scope

There are many constituents in the ecosystem of Japanese construction industry as Figure 5 shows. First of all, construction companies get contracts of construction projects from customers (e.g. expressway company, real-estate company, and government) and manage them. The construction companies compete with each other to establish a position of superiority. A construction company is basically composed of the headquarters and the construction project teams. While the construction project teams actually manage the projects on site, the headquarters is responsible for developing strategies, managing and supporting construction project teams by leveraging resources in the designing department and research institute. Having good relationships between the headquarters and the construction project teams is crucial to achieve success in the projects and sustain competitive position in the industry. Focusing on a construction project, workforce from subcontractors and suppliers of materials and equipment are important constituents, as well as the construction project team. In addition, government is an important composition element not only as a contractee but also as a regulator which establishes and operates laws for both construction industries and general labor regulations.

Among these constituents, a construction project team is identified as an enterprise for transformation in this research. This is because the resisting forces against transformation arise particularly from the construction projects rather than the headquarters, which indicates that transforming the architecture of construction project teams is crucial to transform the construction

industry. The scope of this research is limited to civil engineering projects in that civil engineering projects mainly consist of public works, which are affected by the government and its policy. Also, the relatively longer project duration makes the project teams get left behind the times and technology development easily. In terms of project size, this research mainly focuses on medium to large project which have enough resources to develop or introduce new technologies. In addition, different types of work (e.g. bridge, tunnel, and dam) are included in the scope.

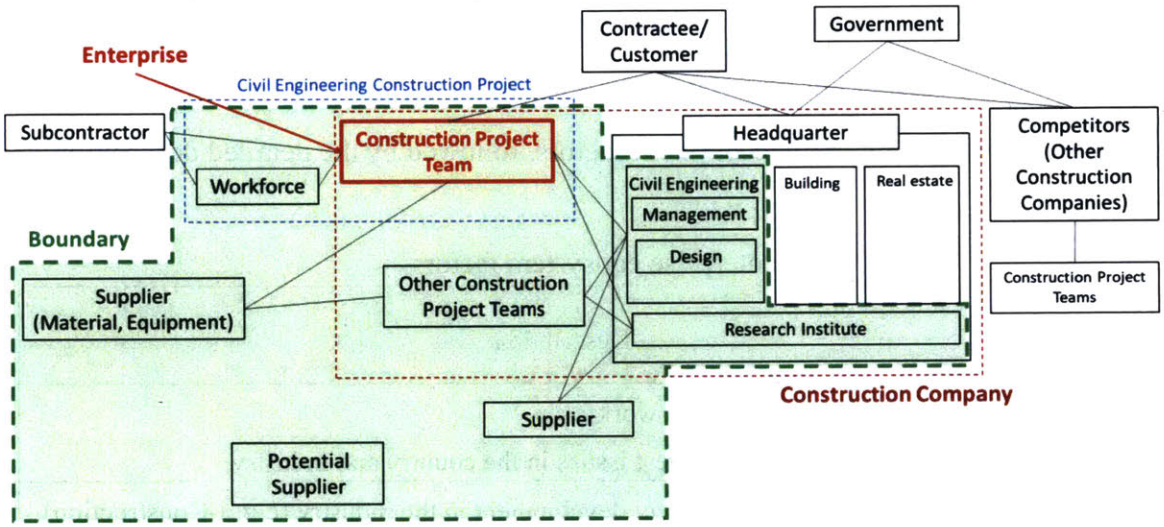


Figure 5: Constituents in the ecosystem of construction industry

In order to design future architecture of a construction project, what is important is considering not only the internal architecture of a single construction project team, but also the relationships with external constituents such as the headquarters, suppliers, workforce, and the other projects. Therefore, the boundary, in other words, the scope for the transformation is identified as Figure 5 shows.

3.2. Enterprise Landscape

Understanding the enterprise landscape is the first step in the ARIES framework. Enterprise landscape is composed of external landscape, called ecosystem, and internal landscape. The ecosystem is the area where the targeted enterprise exists and consists of the entities which

are interconnected with the enterprise. The other entities may include other enterprises and stakeholders such as competitors, suppliers, and government agencies. On the other hand, the internal landscape is understood by looking at fundamental elements and core values inside the enterprise.

3.2.1. External Landscape

The exogenous factors around the enterprise, called ecosystem factors, change over time and put both positive and negative impacts on the enterprise. It is important to understand not only the current state of these factors but also the future state when architecting the expected future enterprise. Table 1 shows six important ecosystem factors, followed by the detailed description.

Table 1: Enterprise ecosystem factors

Ecosystem Factors	Description
Resource	- Aging of population, especially workforce - Overworking is one of the biggest issues in the country and industry
Politics	- Government promotes technology development in the industry (e.g. i-Construction) - Government promotes work style reforms to prevent overworking.
Economy	- The economy of construction industry has been in a depression.
Market	- Large market of technology innovation in construction industry - Stable market of construction inside the company
Technology	- Technology innovations are shifting to mechanization, automation, and digitalization
Regulation	- Government is reviewing new standards for new technologies

- Resource (Important)

Aging of workforce is one of the critical issues in Japan, especially in the construction industry. As of 2013, more than one third of construction workers are older than 55 years old, which means that they will retire in the next ten years. In addition, its proportion has been increasing [12]. This implies that current construction production system will not work in the near

future. Additionally, overworking is a serious problem to be solved in Japan, and the construction industry is no exception. The average working hours per month in the construction industry is second longest of all industries in Japan [13].

- Politics (Important)

In light of the aging of workforce, MLIT, Ministry of Land, Infrastructure and Transport and Tourism, has accelerated a promotion named i-Construction which encourages the construction industry to leverage cutting-edge technologies such as ICT, IoT, and robotics in order to increase productivity of the construction operations. The roadmap of i-Construction says "the goal is to improve the productivity of the construction sites by 20% by 2025 by leveraging ICT and 3D data in construction production process." [14] In addition, the government has been promoting work style reform in order to solve the problem of overworking, especially since 2016 [15]. These factors are driving forces for transformation of the construction industry.

- Economy

The economy of Japanese construction industry including the construction investment and public work budget had been in a depression since 1996. However, it started to recover gradually in 2010 [16]. Although the amount of the current investment is around 60% of the peak, the economic recovery drives the construction companies to establish foundation to invest future development.

- Market (Important)

While it is said that domestic demand for construction project will decrease after the Olympics in 2020, some forecasts say that construction investment in Japan will still be large especially for renewal projects [17]. In terms of market of technology development in construction industry, according to a McKinsey report, the market of construction innovation is large because

of previous underinvestment in R&D and innovation in the industry [18]. For example, the market of AI in Japanese construction industry will be valued 60 billion USD in 2030 while the market in 2015 was valued 800 million USD [19].

- Technology (Important)

Robotics and automation technologies with which human labor can be replaced have grown rapidly. In addition, increase in available data has accelerated development and prevalence of digital technologies such as ICT, IoT, and AI [20]. Especially, the improvement in terms of size, accuracy and cost has driven the rapid expansion [21]. These cutting-edge technologies are considered to be one of the solutions to the aging society and improving productivity in Japan. The examples of application of cutting-edge technology to the construction industry are shown in Table 2.

Table 2: Examples of application of cutting-edge technology to construction industry

Type of work	Conventional method	New method with new technology
Field survey	Technicians use survey instrument such as electronic distance meter.	A UAV takes photo of the field site which has location information [22].
Construction machine operation	A skilled worker rides and operates a construction machine.	One person operates several machines at the same time by using ICT [23].
Installation of rebar	Skilled workers install rebar.	An installing machine helps skilled workers install heavy rebar [24].
Tunnel boring machine operation	A skilled worker operates a boring machine.	AI operates a boring machine [24].

- Regulation

Some standards related to construction design and operation have started to be reviewed and revised by the government in light of the rapid growth of new technologies. For example, a new standard refers to the method of field survey using UAV. Also, quality control using 3D data is integrated into the standard for control criteria [25].

These factors discussed above are not independent but rather interrelated with each other as Figure 6 shows. Aging of workforce, resource issue, drove Japanese government to develop new policies for improving productivity and also accelerate technology development. Also, technology development and politics were affected by the market of the construction industry and the technologies in the industry. Regulation started to be developed as technology became feasible and reliable. Based on this analysis, many factors in external landscape generate driving forces for transformation of the construction industry. Although the standards for leveraging cutting-edge technologies have not been developed enough yet, it will be developed gradually as the technologies are developed and introduced in the construction industry.

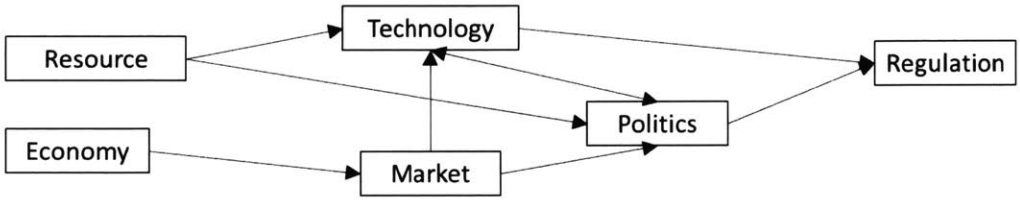


Figure 6: Relationships among enterprise ecosystem factors

3.2.2. Internal Landscape

The internal landscape can be understood by identifying core values, strategic goals, and objectives of the enterprise. Kajima Corporation, one of the largest construction companies in Japan, was founded in 1840. Several basic concepts of Kajima indicate that they put an emphasis on sustainable development achieved by technology development. For example, the corporate philosophy includes "...we pursue creative progress and development founded on both rational, scientific and a humanitarian outlook, ...[26]" In addition, Kajima has their own spirit named enterprising spirit, which is always on display as the company takes on challenges using new technologies. These corporate philosophy and spirit have an impact on their strategic goal, sustainable development. In light of the change in the Japanese construction market such as aging population and limited pubic spending, Kajima is making efforts to make its construction business

more competitive by improving work efficiency through mechanization, automated construction, and using IoT and AI technologies [27]. Especially, in the civil engineering department, they recognize that it is necessary to integrate companies and people with requisite skills in a timely manner rather than to try to develop everything by ourselves.

Additionally, it is necessary to understand the targeted capability to achieve the strategic goal. Table 3 shows the targeted capabilities to achieve Kajima's goal, sustainable development by leveraging cutting-edge technologies.

Table 3: Capabilities of the company

Capability	Description
Agility	Need to shift rapidly to catch up with rapid development of technologies
Replicability	Need to expand to the construction projects distributed all over the country
Competitiveness	Need to gain an advantage over competitors who try to transform as well
Adaptability	Need to respond to changes in its ecosystem, especially technology development
Evolvability	Need to transform by leveraging the successful feature of the current architecture (e.g. Expertise and experience in the construction fields)

- Agility

As discussed repeatedly, the technologies have been developed rapidly year by year. In order to catch up with the rapid technology development, it is necessary for construction project teams as well as the headquarters of the company to shift the mindset from maintaining conventional methods and technologies to developing and leveraging new technologies.

- Replicability

Replicability means that the companies can distribute one technology used in one project to the other projects. The construction companies have many construction projects distributed all over the country. One of the advantages of having many projects is that the company can extend a

technology developed in one project to many other projects, which contributes to developing and spreading the technology rapidly and effectively. For example, considering that AI needs a lot of data to develop itself, a lot of data in different construction projects enables AI to perform robustly in different conditions [19]. Therefore, replicability is important in that the construction companies can leverage their advantages of having many projects.

- Competitiveness

The competitors are also trying to transform themselves in light of the driving forces in the external landscape of Japanese construction industry. Therefore, providing greater value to stakeholders by technology development is key to achievement of the competitive advantage.

- Adaptability

The ecosystem around the construction industry including economic condition, government policy, regulation, and the speed of technology development, is not stable, but rather changes over time. The company needs to change their strategies and architectures continually and flexibly in response to the change of the ecosystem.

- Evolvability

Leveraging successful features of the current architecture as well as introducing new technologies is key to transformation. For example, construction project teams have a vast amount of experience in construction projects. These experiences can be leveraged when using and developing cutting-edge technologies from different domains.

To summarize the above analysis and discussion, although the strategic goal and objective are adequately set, currently the company needs to improve the capabilities mentioned above in order to achieve the targeted goal.

3.3. Stakeholder Analysis

Performing stakeholder analysis is the second step of ARIES framework. An enterprise coexists with stakeholders which affect and are affected by the enterprise inside its ecosystem. When analyzing the relationships with the stakeholders, it is important to consider value proposition. In other words, "What does the enterprise do for a stakeholder?" and "What does the stakeholder do for the enterprise?" are key questions to understand the relationships with the stakeholders. Additionally, an enterprise consists of several stakeholders, called internal stakeholders [1]. Understanding internal stakeholders is important to figure out how the enterprise functions as a system. In this chapter, the relationship between the enterprise and the external stakeholders is described as stakeholder map at the beginning. In addition, the importance and the performance of the external stakeholders are discussed, which helps to identify the current architecture and set desired state easily. Finally, the internal stakeholders of the enterprise are discussed from the perspective of connection with external stakeholders.

3.3.1. External Stakeholder

The first step of stakeholder analysis is identifying all stakeholders. By reference to Figure 5, seven external stakeholders are identified: Headquarters, Subcontractor, Workforce, Customer/Contractee, Supplier, Government, and Other project teams. The next step is identifying the relationships of the enterprise with these stakeholders in terms of value exchange. Stakeholder map is one of the effective tools to represent the stakeholders and the value flows in a single diagram. Figure 7 is the stakeholder map around the construction project team, created based on the author's experience. While value flows are classified in different ways from research to research [28] [29], the flows in Figure 7 are simply classified into three in this analysis, which makes it easy to capture the flows.

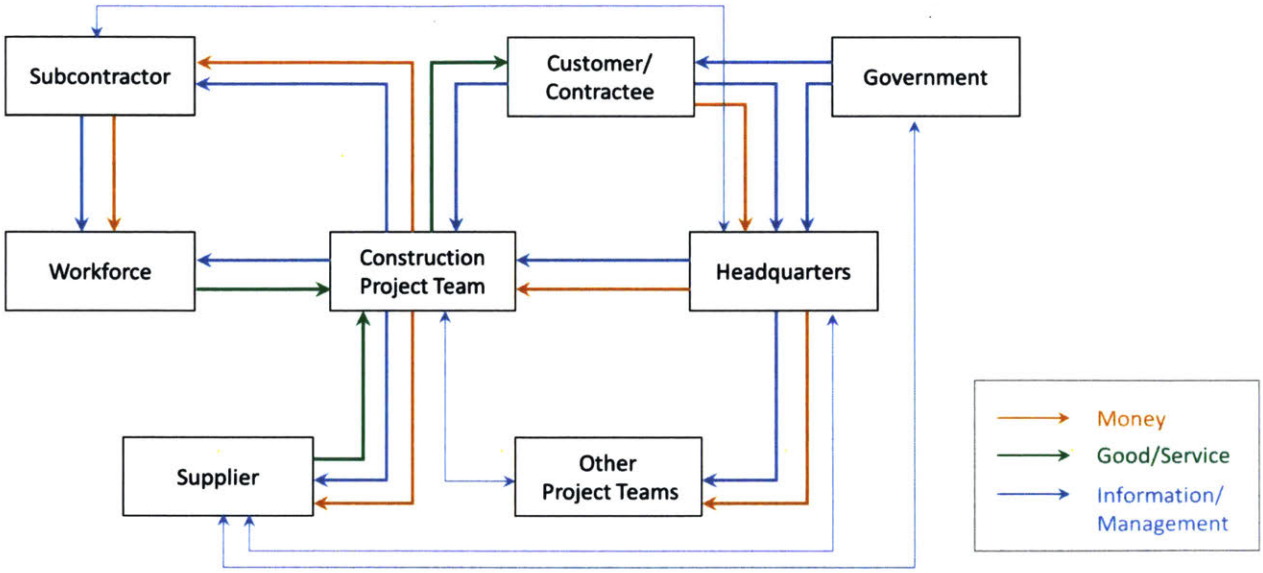


Figure 7: Stakeholder map (external)

First, the orange arrows show the money flow. It is easy to capture that money is flowed from customer to supplier and workforce via the headquarters and the construction project team. Second, the green arrows show the flows of goods and services. The construction project team delivers final products such as bridge or dam as a value to the customer, which is constructed by workforce's operation and materials and equipment from suppliers. Third, the blue line shows the flows of information and management consisting of various components. Customers and the headquarters provide information about the construction project to the project team and manage the progress of the project. Also, the project team shares the information with subcontractors and suppliers so that the team can ensure appropriate workforce, materials, and equipment when needed. In the daily operation in the project site, the project team provides workforce with information to manage the daily progress. The policy developed and announced by government is also included in the information flow. While the bold arrows show the main value flows among stakeholders for the project which the team is involved, the thin two-way arrows show the information flows between stakeholders which are important outside the project. For instance, the headquarters exchanges information with subcontractors and suppliers to understand their capacity

and capabilities for the future projects. Also, government collects information from suppliers to develop the standards for new technologies. Exchanging information with other project teams is also important in that the technology applied to one project has potential to be applied to the other projects.

The importance of the relationship is different from stakeholder to stakeholder. Table 4, created based on the author's experience, shows the importance of stakeholders in terms of technology development in the construction project. In Table 4, what the upper right half shows is different from what the lower left half shows. For example, while the first row shows how much the seven external stakeholders are important to the construction project team, the first column shows how much the construction project team is important to each external stakeholder. What is interesting is that the results from these two perspectives are not always same. For example, based on the numbers in the table which correspond to the degree of importance, the construction project team is regarded less importantly than the team regards the other stakeholders. This is because the construction project team is just one of many projects for customers and government. On the other hand, customers are regarded more importantly by other stakeholders because the technology development in the project is affected by the budget from customer.

Table 4: Importance of stakeholders (external)

	Construction Project Team	Workforce	Subcontractor	Headquarters	Customer/Contractee	Government	Supplier	Other Project Teams	Score(B)
Construction Project Team		H	M	H	H	M	H	M	18
Workforce	H		M	L	L	L	M	L	11
Subcontractor	M	M		L	L	L	L	M	10
Headquarters	H	M	M		H	M	M	H	17
Customer/Contractee	M	L	L	M		M	L	L	10
Government	L	L	L	M	M		M	L	10
Supplier	H	M	L	H	M	M		M	15
Other Project Teams	M	L	L	H	L	L	M		11
Score(A)	16	12	10	15	13	11	13	12	
Score(A)-Score(B)	-2	1	0	-2	3	1	-2	1	

H High: 3
M Medium: 2
L Low: 1

When analyzing the current situation of the relationships between stakeholders, it is important to compare the importance of the stakeholders with the performance. Figure 8 shows the two factors in one diagram.

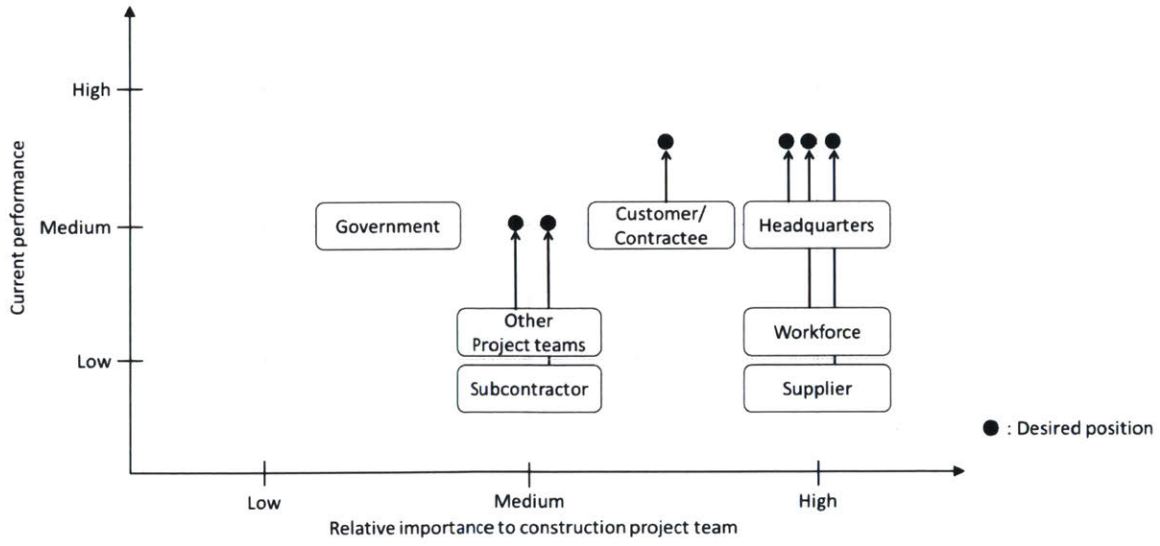


Figure 8: Relationship between importance and performance of the stakeholders

- Headquarters

The headquarters is important in that it supports the project team in terms of budget, resource, and information. Although the headquarters started to collaborate with the project team for technology development, it does not work well enough currently. For example, the idea and information provided by the headquarters do not always meet the needs of the project team. The performance of the stakeholders was evaluated based on the author's experience.

- Workforce

Workforce is an important stakeholder in that they perform actual operation in the field sites and they have experience in the field operation which can be leveraged when developing technology. However, they do not always acknowledge the value of cutting-edge technologies and recognize the necessity of the change from the current state.

- Supplier

Suppliers play an important role in bringing cutting-edge technologies into the construction sites. Although some suppliers are dedicated to technology development, the construction project team tends to have relationships with suppliers only related to the construction industry. Considering that the technologies in different domains have potential to be applied to construction sites, the current performance is low.

- Customer/Contractee

While customer is important for the enterprise in that it has potential to support technology development in the project in terms of budget and information, the enterprise is not so important for the customer in that technology development in the project does not always have direct impact on the customer in the short term. In terms of performance, although customer is getting interested in technology innovation in the construction sites in light of the policy promoted

by government, it has not moved to enough concrete actions yet.

- Subcontractor

Although subcontractors are not directly involved in actual operation of the project, they play an important role in incentivizing workforce to try new technologies and sharing their experience with the project team. However, currently they do not have enough motivation for transformation as well as knowledge other than the construction industry.

- Other project teams

Although the other project teams do not have strong direct relationship with the targeted project team, they are important in terms of sharing information about new technologies and having potential to expand the technology developed in the project to the other project sites. Currently, each construction project tends to focus on managing their own project rather than collaborating with the other project teams, resulting in the low performance.

- Government

The importance of government is between medium and low in that government is responsible for developing standards for application of new technologies but a construction project team is just one of many construction projects for government. Although government is still halfway through reviewing current standards and revising them for new technologies, it has already developed fundamental policies to promote technology innovation in construction industry. Therefore, the current performance of government is medium.

Figure 8 not only shows the current performance of the stakeholders schematically but also helps to identify the desired states as black circles show. The desired performance are set based on the importance of the stakeholders. In other words, the more important the stakeholder

is, the better it should perform. This diagram will be helpful to identify envisioned future and generate alternative architectures.

3.3.2. Internal Stakeholder

Understanding internal stakeholders is also key to figuring out how the enterprise works as a system. The internal stakeholders of the enterprise are added to the external stakeholder value network as shown in Figure 9. Basically, the civil engineering construction project team consists of directors and three sub-teams: civil engineering, M&E, machine and electricity, and administration. Figure 9 indicates that each external stakeholder has a relationship with the specific internal stakeholders in terms of information flow. For example, while the headquarters and customer are generally connected with director, subcontractors have relationships with senior managers. Also, while workforce is related with assistant managers, suppliers have connections with both senior and assistant managers in civil and M&E teams. Additionally, subcontractors and workforce have relationships with both civil and M&E teams. These characteristics indicate that cooperation across positions and sub-teams is important for the enterprise to function as a system.

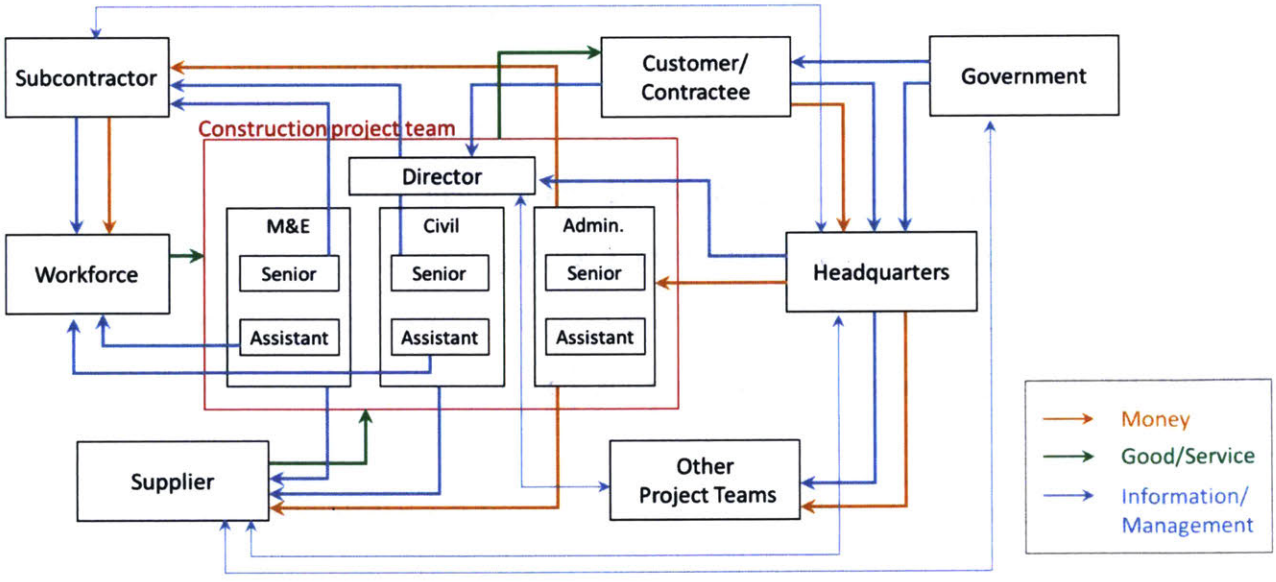


Figure 9: Stakeholder map (external + internal)

When focusing on the internal stakeholders, there are multiple information flows across positions and sub-teams as Figure 10 shows. Integrating Figure 9 and Figure 10, these arrows in Figure 10 play an important role in sharing the information received from the external stakeholders with the internal stakeholders. For instance, the information from workforce is transferred from assistant managers to other members. In a similar way, the information from headquarters and customer is shared across the entire enterprise by directors.

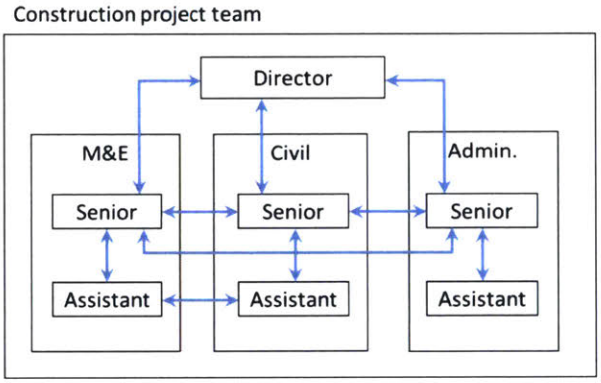


Figure 10: Stakeholder map (internal)

To summarize the above analysis and discussion, stakeholder analysis provides two important findings. First, the relationship between the importance and current performance of stakeholders guides identifying the desired state. Second, the integration of internal and external stakeholder value networks indicate how the enterprise works with external stakeholders in its ecosystem as well as the enterprise functions as a system.

3.4. Current Architecture

Capturing the current architecture is the third step of ARIES framework. Understanding the enterprise as it is currently is a powerful guide to creating the future vision and generating alternative architectures. When understanding the current architecture of the enterprise, ten elements described in ARIES framework serve as useful lenses to view the enterprise holistically [1]. In this section, the enterprise is viewed from the ten elements and the interrelationships among

the elements are also discussed. In addition, SWOT analysis is performed based on the ten elements analysis.

3.4.1. Current State in View of Ten Elements

Ten elements are useful to view the enterprise holistically. Considering that the final deliverable of the construction project is a physical construction that is product rather than service, nine elements except service are used in this analysis. Table 5 shows the summary of the enterprise's current states from the nine viewpoints followed by the detailed description of each element.

Table 5: Ten elements of the enterprise

Element	Description
Ecosystem	- Most ecosystem factors drive the stakeholders to promote technological innovation in the construction industry.
Stakeholder	- Stakeholders establish a consortium to develop and introduce new technologies collaborately. - They have not involved the companies and suppliers from different industries yet.
Strategy	- There exists a conflict of strategy between the construction project team and the headquarters.
Information	- The team has strong networks of existing technologies in the industry. - The team does not have enough networks for collecting new technologies.
Infrastructure	- The construction site is a valuable place to examine new technologies. - ICT infrastructure (e.g. CIM, 3D CAD) has not been in widespread use yet.
Product	- The performance of the product and its process are affected by The techologies used during construction. (e.g. schedule, cost, quality, and safety)
Process	- The team needs to collaborate with the external stakeholders such as headquarters, customer, and regulators in developing and introducing new technologies.
Knowledge	- The team has rich knowledge and experience of construction. - The team does not have enough knowledge about cutting-edge technologies in different domains.
Organization	- The team has a strong internal relationships while the external relationships are weak. - Long working hours prevent the employees from learning and trying new things - In terms of working culture, the team has the resisting forces for change.

- Ecosystem

As discussed in section 3.2.1. External landscape, there are many driving forces for transformation of the construction industry in the ecosystem around the construction project team. The estimate of decreasing workforce in the future and rapid technology development drove Japanese government to promote i-Construction. Since the cutting-edge technologies has not been introduced and applied enough to the construction industry yet, the large market stimulates suppliers which have applicable technologies. Additionally, economic recovery in Japanese construction industry gives construction companies an extra margin to invest technological development. Although the standards for new technologies have not been developed enough yet, government has been developing and revising the standards at an unusually rapid pace [30].

- Stakeholder

As described in section 3.3. Stakeholder analysis, the construction project team is interrelated with several external stakeholders. It is noteworthy that the external stakeholders have started to promote technological innovation in the construction industry. One of the biggest actions is forming a consortium, named i-Construction driving consortium, in reaction to i-Construction promoted by the government. The consortium consists of some external stakeholders as Figure 11 shows and makes it a goal to increase productivity in construction field sites by introducing cutting-edge technologies such as IoT and AI. To take an example, the consortium holds pitch events in order to strengthen a connection between the construction industry and the cutting-edge technology suppliers [31].

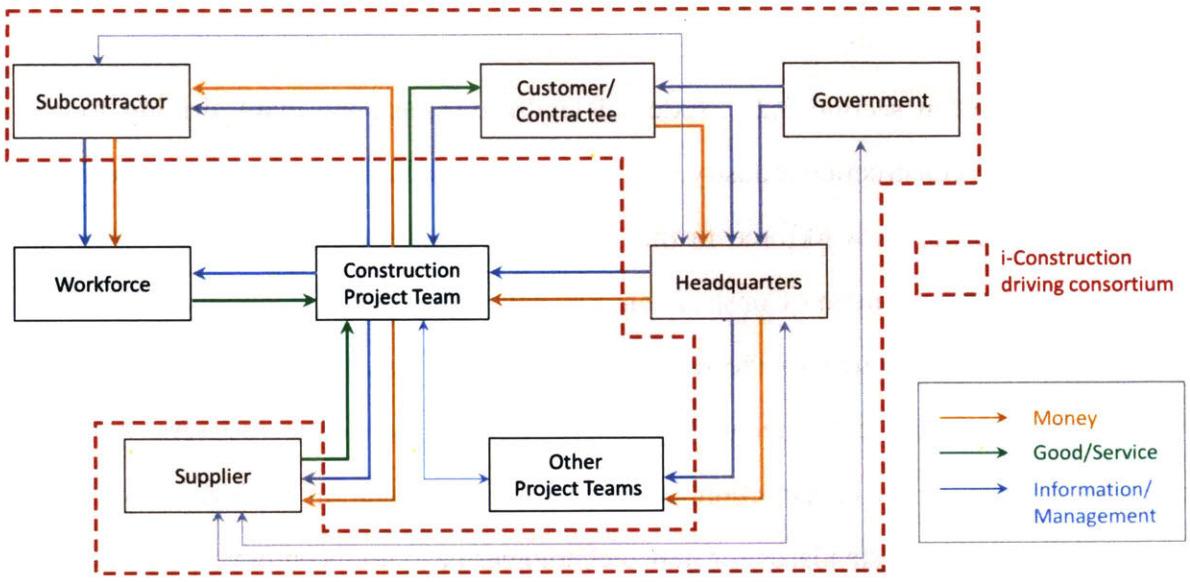


Figure 11: i-Construction driving consortium (adapted from Figure 7)

However, it does not work well from the perspective of the construction project team. First of all, the needs of the construction fields are not identified enough. In the pitch events, many of the presenters are from government and contractee, which mainly focus on the entire process of construction, from design phase to maintenance, rather than construction operation in field sites [32]. In addition, the consortium mainly consists of companies in the construction industry and the number of companies from other industries is small [33], which indicates that the construction companies and their construction project teams do not have enough relationships with the companies in different industries which have cutting-edge technologies. In light of this situation, construction companies started to build connection with the companies in different industries by themselves. For example, Kajima Corporation established a small hub in Silicon Valley in 2018 to find startups which have cutting-edge technologies and build relationship with them [34]. Additionally, some Japanese startups went into the construction industry and started to build connection with construction companies to leverage their leading-edge technologies [35] [36]. While the construction companies, especially the headquarters, started to build relationships with other industries, the construction project team still does not have enough relationships with other industries.

- Strategy

As described in section 3.2.2. Internal landscape, the construction company, especially the headquarters, has an emphasis on sustainable development from a long-term standpoint and achieving advantage over the competitors by technological development. In order to achieve the goal, the headquarters started to promote technological innovation in the construction sites. On the other hand, the goal of the construction project team still tends to be set from a short-term standpoint, which is to complete the project within the assigned timetable, with high quality, without any accidents, and inexpensively. Therefore, the goal of the construction project team is not always consistent with the goal of the headquarters.

- Information

Since the construction team has strong relationships with subcontractors and suppliers which they have known for a long time, the team can collect information from them frequently. However, the subcontractors and suppliers are mainly specialized in construction, so the team is not likely to get enough information about cutting-edge technologies in different domains from them. In light of this situation, it is valuable for the construction project team that the headquarters started to promote technological innovation in the construction sites and share information with the project teams. In addition, JSCE, Japan Society of Civil Engineer, started to hold seminars about new technologies such as CIM, robotics, and ICT [37].

- Infrastructure

In terms of infrastructure, a construction site is an effective place for technological development in that the technologies can be tested in the actual field as well as many needs for technological development and useful data exist in the sites. For example, the data of actual machine operation by skilled operators can be obtained in the field sites in order to develop automatic operation system which replicates the operation of skilled operators [38]. Also, the

examination of a new technology in the site makes the developers find out the necessity of another new technology. For example, in a field test of automatic operation system of construction machines, the developers found that AR technology for visualizing the progress of the automatic operation system needs to be developed so that workforce and managers can see the progress as they installed the landmarks to see the progress in the conventional method [39]. Although a construction site is a good place for technology development, it is worth noting that the goal of the construction project team is to complete the project rather than to examine new technologies as mentioned in the strategy section.

As for information technology, the infrastructure around the construction project team has not been developed sufficiently yet. For example, while some of the new technologies need specific software such as BIM, CIM, or 3D CAD where the data is stored and processed [40], many of the construction teams do not have suitable software for them currently. In addition, since no IT engineers are assigned to the construction project team in general, it is difficult for the team to set up IT infrastructure, especially when introducing new technologies.

- Product

The product for the construction project team is a construction product such as bridge, tunnel, and dam. As described in the strategy section, the construction project team is responsible for completing the project and meeting the requirements for schedule, quality, cost, and safety. While new technologies may have potential to perform better than the conventional technologies, they may work poorly especially in their development phase, which is the risk for the construction project team.

- Process

When introducing or developing new technology in the site, the construction project team

is usually required to collaborate with the headquarters rather than do it alone. For one thing, the team needs financial support from the headquarters due to limitation the budget of the project. Another reason is that the headquarters is more familiar with the new technologies and checks whether the project team chooses the appropriate technology or not. In some cases, the project team needs to work with the customer/contractee as well as the headquarters when the team develops new technology with the customer. In addition, the team is required to work with regulators especially when the technology has a safety risk and the standard has not been established yet [21].

- Knowledge

Knowledge and experience in construction field sites have accumulated for a long time and handed down from person to person working in the sites [20]. While the accumulated knowledge and experience are specialized in construction and civil engineering, the construction industry does not have enough expertise and experience in other domains. According to the result of the questionnaire shown in Table 6, 25.3% of respondents are concerned about the shortage of human resources who can handle new technologies and 18.5 % of them are concerned about that some engineers and workforce cannot respond to new technologies [24].

Table 6: Challenges and barriers in improving productivity [24]

Challenge and Barrier	Proportion
Introduction cost for equipment and technologies	34.4%
Shortage of human resources who can handle new technologies	25.3%
Decrease in technical capabilities due to over-dependence on tools	25.3%
Need for significant revision of current contract systems and standards	19.4%
Limited effectiveness due to diversity of the conditions in the sites	19.4%
Increase of people who cannot respond to new technologies and systems	18.5%
Constrained environment (e.g. weather, land features)	14.4%
Only achievement of efficiency in individual task, Failure in total optimization	13.5%
Forces against introducing new technology and system in the sites	8.8%
Many places still need conventional technology instead of new technology	8.8%

(N=340)

- Organization

In this section, the organizational structure, working environment, and working culture are described. As Figure 12 shows, the company has a matrix organization structure which is composed of product and functional structure. While the employees are assigned to the project team, the company has several functions such as civil engineering, machine and electronic engineering, and administration. As such, each employee in the team needs to report to both the director of the team and the headquarters. However, the connection inside the team is generally stronger than the connection with headquarters due to the place people work. Since construction work is operated in the site which is far from the headquarters, the construction team builds a temporary office near the site and work there together, which enhances communication inside the team rather than outside the team. Due to this structure, when the team addresses the problem which the members are not familiar with, the team does not perform well. For example, although the necessity of the ICT engineer in the team is recognized [37], there are no ICT engineers in a typical construction project team. Therefore, it is difficult for the project team to introduce and manage new ICT technologies.

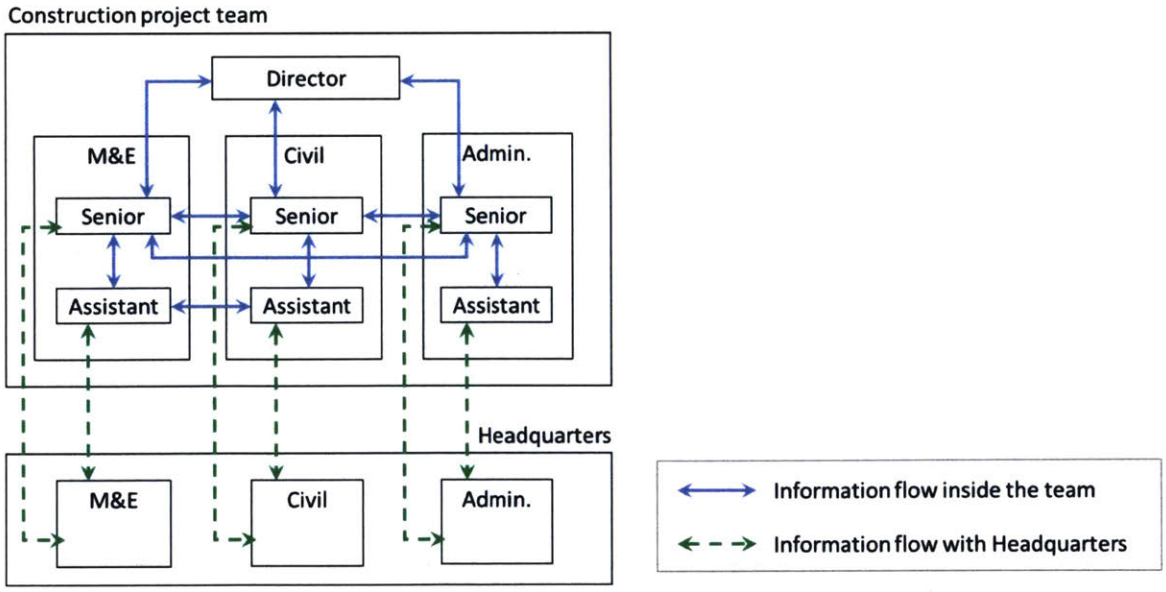


Figure 12: Information flow inside the company

As for working environment, one of the characteristics of the construction project team is long working hours. In 2017, only 16.7% of all the employees in Japanese construction industries can take two days off every week. This is because the amount of work per one employee is currently larger than before, which requires the employees to do more paper management as well as go into the site [21]. Although improving productivity is effective to reduce working hours, 35.6% of the companies are too busy to do anything related to i-Construction [41], which indicates that the construction team does not have enough time to learn and try new things.

The unique organizational structure and working environment have created the distinct working culture. First of all, the construction project team is reluctant to change conventional methods. Many articles illustrate the cases where the construction project team refused to accept introduction or experiment of new technologies in the field site despite the headquarters is eager to do it [19] [24]. This resisting force is also shown in Table 6. The resisting force is stronger in large and established companies which have long history and accumulates successful experience. Another characteristic is that the construction company and the project team tend to acknowledge the value of new technologies once they were demonstrated in many cases. Table 7 shows the technologies that the employees of the construction companies think to be helpful to productivity improvement. Among the listed technologies, UAV and ICT construction machine have higher adoption rate because the government put an emphasis on applying them to earthwork projects in the early stage of i-Construction [14]. Also, CIM started to be leveraged in 2014, before i-Construction was launched [42]. On the other hand, many new technologies listed in other options in Table 7 such as AI and IoT have not been adopted enough yet compared with UAV, ICT construction machine and CIM. This indicates that the employees of the construction companies do not regard those technologies as reliable since they have not seen a lot of actual achievement as well as they do not have sufficient knowledge about them.

Table 7: Technologies thought to be helpful to productivity improvement in civil engineering [24]

Technology	Proportion
Implementation of precast components	43.2%
UAV	41.0%
ICT construction machine	30.2%
CIM	27.3%
Construction robot	24.5%

[Other options]

- AI
- IoT
- 3D laser scanner
- Non destructive inspection
- Image recognition
- 3D printing
- Power assist suit
- VR
- AR
- Wearable computer

(N=139)

From another angle, the culture of the construction industry is different from the other industries which possess cutting-edge technologies. For example, a Harvard Business School case about Valve Corporation points out the cultural difference between software and hardware industry. The case study says that hardware production needs upfront investment and long lead-time, and requires specification to be fixed long in advance of release because it is quite difficult to fix the problems once the products are released. On the other hand, software services tend to be released earlier and improved constantly based on the real-time feedbacks due to the ease of updating remotely [43]. From this perspective, the construction industry has hardware culture in that the final deliverable of the construction industry is construction product and it is difficult to fix extensively once it is completed although it needs some periodic inspections and maintenance after completion. Therefore, people working in the construction industry tend to hesitate to try new things without having certainty about them.

3.4.2. SWOT Analysis

SWOT analysis is an effective tool for organizing the results of the current-state investigation described in section 3.4.1 in that SWOT analysis involves identifying both the external and internal factors that provide either advantages or disadvantages to achieving the goal [1]. The factors described in section 3.4.1 are categorized in accordance with the characteristics of each element. The factors from the perspective of organization, knowledge, information, and infrastructure are described in strength and weakness in that they are internal factors. On the other

hand, the factors from the perspective of ecosystem, stakeholder, strategy, process, and product are described in opportunity and threats in that they are external factors. The result of SWOT analysis is summarized in Table 8, followed by the detailed description of each aspect. In the detailed description, the relationships between factors are also discussed.

Table 8: SWOT Analysis for current architecture

Strength	**Weakness**
- Dense networks inside the team **[Organization]** - Rich knowledge and experience in the site and construction **[Knowledge]** - The site is a good place for technology development **[Infrastructure]**	- Weak networks outside the site **[Organization]** - Lack of time to learn and try new things due to long working hours **[Organization]** - Reluctance to change conventional ways **[Organization]** - Lack of knowledge about new technologies **[Knowledge]** - Lack of information for new technologies **[Information]** - Lack of ICT engineer and infrastructure in the site **[Infrastructure]**
Opportunity	**Threat**
- Ecosystem factors drive innovation in the construction industry **[Ecosystem]** - i-Construction consortium works actively **[Stakeholder]** - Headquarters becomes dedicated to technology development in the site **[Stakeholder]** - New technologies have possibilities to generate positive effects on the product **[Product]** - Headquarters support the team in the process of technology development **[Process]** - There are many construction sites across the country for expansion of the technologies **[Stakeholder]**	- i-Construction consortium does not have enough connection with other industries **[Stakeholder]** - Conflict of the strategies between the project team and the headquarters **[Strategy]** - New technologies have risks to generate harmful effects on the product **[Product]** - Collaboration with stakeholders in the process takes time **[Process]** - The rise of competitors which do not have enough experience but have new technologies **[Stakeholder]**

- Strength

The strength of the construction project team is the tight networks inside the team created in the project office which is located away from the headquarters. These strong networks enhance sharing rich knowledge and experience in the site. In addition, the project site where the project

team spends most of their time is an advantage in that the team is able to capture the real needs for new technologies in the site as well as test them there. Understanding needs properly is crucial in technology development. The technologies developed without setting needs properly tend not to be put to practical use [44].

- Weakness

In contradiction to the dense networks inside the team, the networks with external stakeholders are weak, resulting in the lack of information about new technologies from the external stakeholders such as the headquarters and suppliers in different industries. Due to lack of information, the team has fewer opportunities to learn about new technologies. In addition, scare prevalence of ICT infrastructure, such as 3D CAD and CIM, as well as lack of ICT engineers in the site lead to fewer opportunities for the team to try new ICT technologies to gain practical knowledge. Another cause for lack of knowledge is long working hours that provide the team with less time to try and learn new things, despite trying and learning new things takes time. Finally, the combination of lack of knowledge about new technologies and rich experience in the conventional ways fosters the reluctance to change the conventional ways from the cultural perspective.

- Opportunity

Many ecosystem factors drive the stakeholders to technological innovation in the construction industry as the example of i-Construction consortium illustrates. In addition, headquarters becomes dedicated to technology development in construction sites, which supports the construction project team in that the headquarters shares information and resources with the team in the process of technology development. As for the impact on product, technology development may have positive impacts on the construction product as final deliverables of the project in terms of quality, schedule, cost, and safety. Finally, from the perspective of the

construction company, possessing many construction sites across the country is advantageous in that the company can expand the new technologies developed in one site to the other sites.

- Threat

Although i-Construction consortium works actively, the consortium does not have enough connections with the leading–edge technology suppliers from different industries. In terms of stakeholder and process, the collaboration with external stakeholders in the process of technology development may take longer time and prevent rapid development. The conflict of the strategies between the project team and the headquarters is also a threat. While technology development in the site may be beneficial in the long run from the standpoint of the headquarters, the project teams (which puts an emphasis on completing the project itself) have concerns that the new technologies have risks to generate harmful effects on the product as their final deliverable. From the perspective of the construction company, the rise of competitors that do not have enough experience but have new technologies is a threat.

3.4.3. Interrelationships among Elements

As described in section 3.4.2, the factors viewed from each element are related with each other. Figure 13 shows the interrelationships among elements based on the description in section 3.4.1 and 3.4.2.

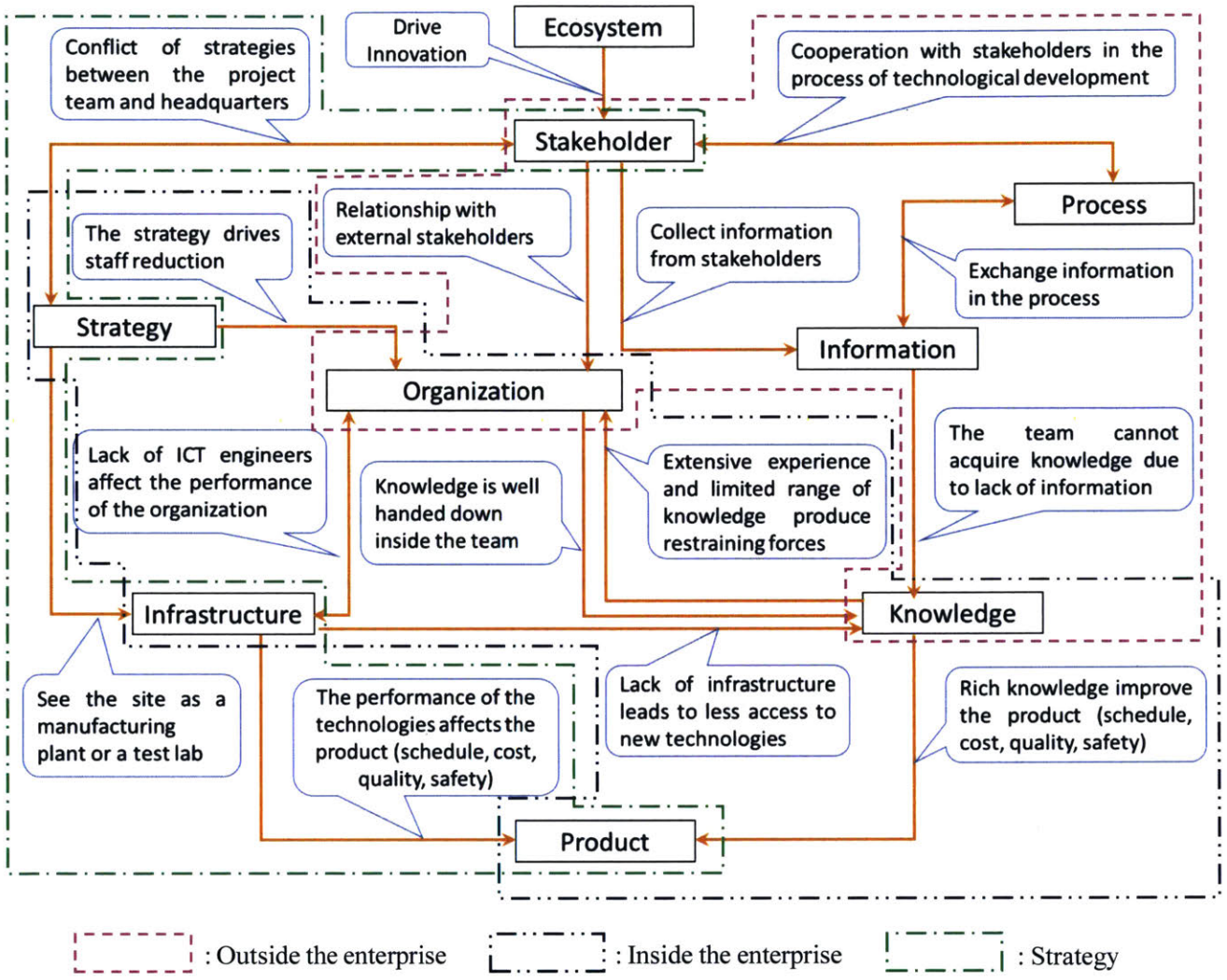
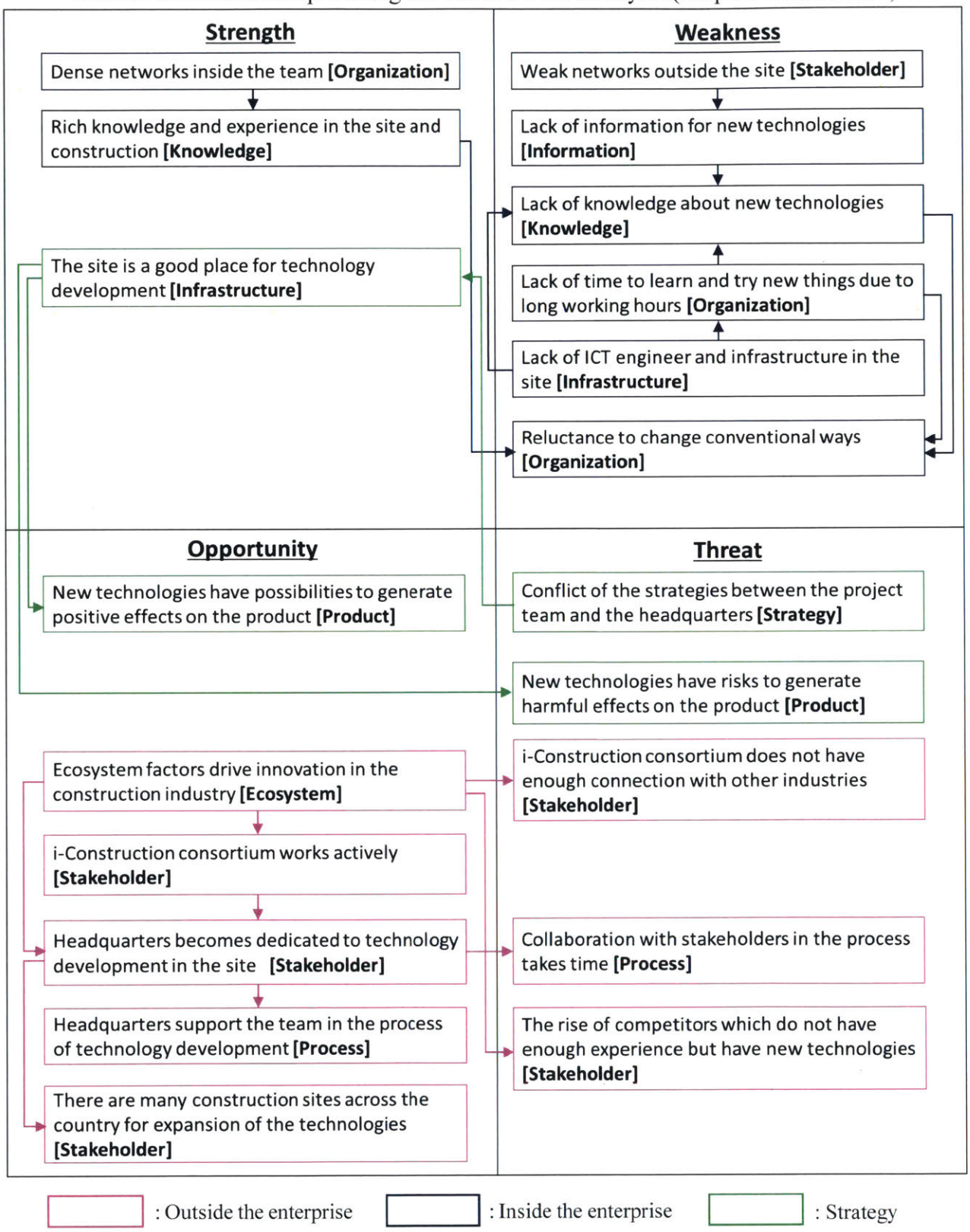


Figure 13: Interrelationships among elements

Although there are many interrelationships among elements, they can be categorized into three groups as Figure 13 shows. First group consists of the factors outside the enterprise, which are related to how the enterprise collects information about new technologies by interacting with external stakeholders. In contrast, the second group consists of the factors inside the enterprise, especially about the working environment, culture and knowledge the enterprise currently possesses. Third group involves the factors related to the conflict of the strategies between the headquarters and the project team, which affects the product as final deliverables for the enterprise.

Figure 13 is a helpful guide to capturing general relationships among elements. However, since each element has multiple factors, it is difficult to figure out which factor of the element affects the factor of another element. In addition, the arrows connecting the elements do not show whether it has a positive or negative impact. In order to understand the interrelationships among factors of the elements, Table 9 was created by integrating the Table 8 and Figure 13.

Table 9: Interrelationships among factors in SWOT Analysis (adapted from Table 8)



The three classifications of the factors in Table 9 correspond to those in Figure 13. As Table 9 shows, the factors are interrelated with each other. For example, the weak connection of the enterprise with the external stakeholders leads to lack of information about new technologies, resulting in lack of knowledge of new technologies. Also, the combination of lack of knowledge about new technologies and rich experience in construction contribute to the culture, the reluctance to change conventional ways. As for the external factors, the ecosystem factor affects the factors related to stakeholders and processes, which are both favorable and unfavorable to achieving the goal.

Table 9 is compatible with Force field analysis as well. While the strength and the opportunity correspond to driving force, the weakness and the threat correspond to restraining force. Also, while the strength and the weakness are internal forces, the opportunity and the threat are external forces. As such, from the perspective of SWOT analysis, enhancing the strength and opportunity and mitigating weakness and threat are key to success in the transformation.

3.5. Holistic Vision of the Future

Creating a holistic vision of the future is the fourth step of ARIES framework. The context factors described in section 3.2 are important to create the envisioned future. Also, it is important to anticipate how the stakeholder values shown in section 3.3 shifts as the transformation progresses. In addition, viewing the enterprise from the perspective of ten elements described in section 3.4 is helpful in that some specific elements may be key to realizing the holistic vision [1]. In this section, the high level vision of the enterprise is described, followed by the details for the envisioned future from the viewpoint of ten elements. Finally, the evaluation criteria of the alternative architectures are set.

3.5.1. High Level Vision

As the first step of creating the holistic vision, the corporate vision is described and how

the enterprise contributes to the corporate vision is discussed. As shown in section 3.2.2 Internal Landscape, Kajima Corporation puts an emphasis on sustainable development achieved by technology development. Also, Kajima has set enterprising spirit as the philosophy, in which the company has been taking on challenges using new technologies. In order to achieve sustainable development as goal, the company needs to improve five capabilities shown in Figure 14, where the relationships among the capabilities listed in Table 3 are represented.

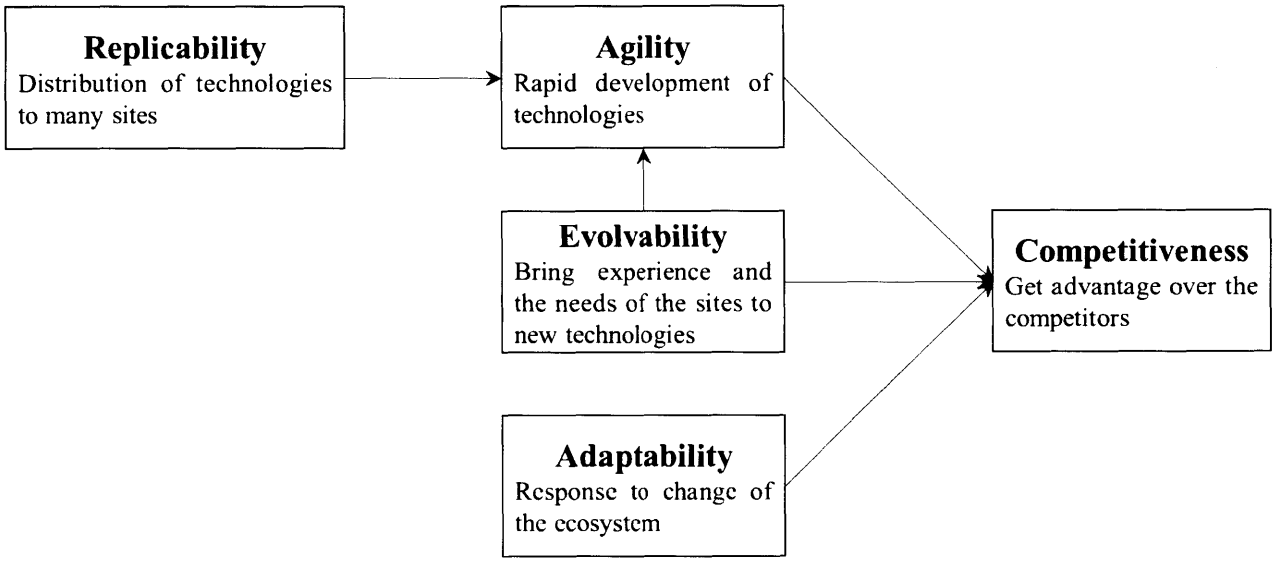


Figure 14: Interrelationship among the capabilities of the construction company

In order to get advantage over the competitors in the construction industry, the company needs to improve competitiveness achieved by improving agility, evolvability, and adaptability. First, agility is the capability to develop new technologies rapidly as well as catch up with rapid technology development. Second, evolvability means in this context that the company can develop technologies which meet the needs of the sites and leverage the knowledge and experience in the site. Evolvability also affects agility in that meeting needs of the site shortens the development time by reducing rework. Third, adaptability is the capability to respond the changes in the surrounding ecosystem. Finally, replicability is the other important capability in that having many

projects all over the country allows the company to expand a new technology in one project to the other projects, which also contributes to increasing agility.

Considering that the enterprise, the construction project team, is an important component of the company, it is crucial to figure out how the enterprise affects the capabilities of the company. The blue boxes in Figure 15 represent the desired states of the enterprise which contribute to improvement of the capabilities of the company.

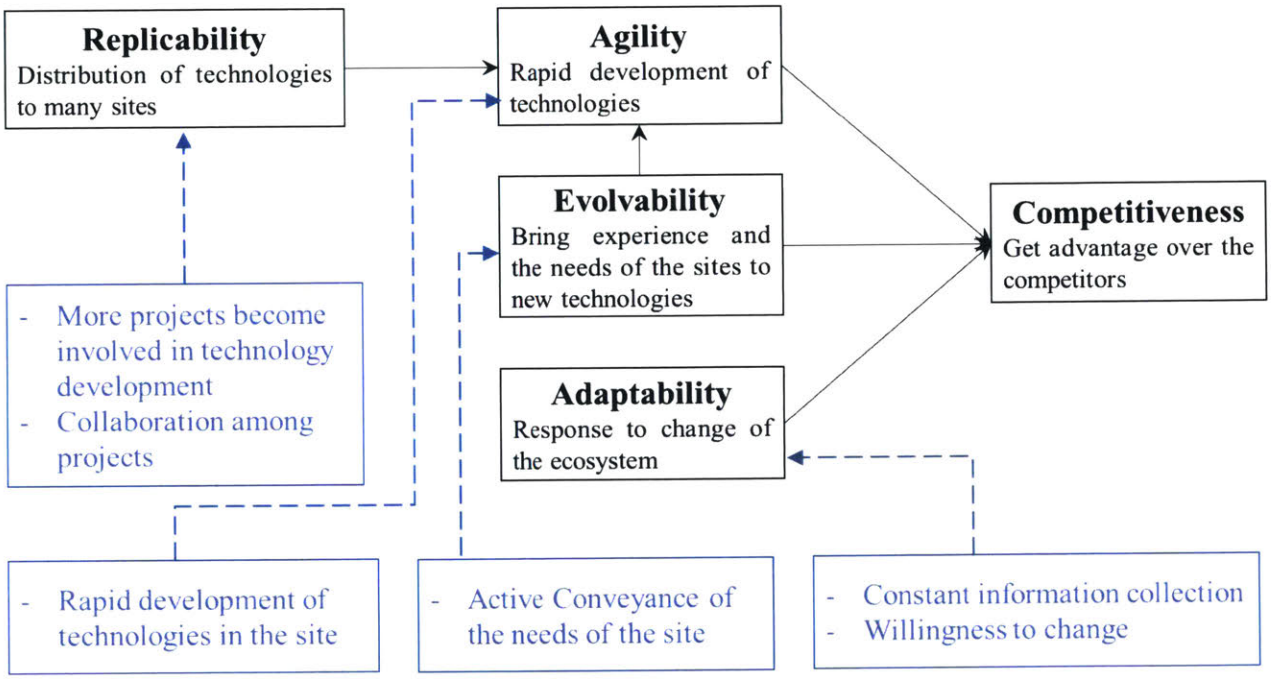


Figure 15: Effects of the enterprise on the capabilities of the company (adapted from Figure 14)

First of all, as for replicability, the more project teams start technology development in the sites, the more rapidly the technologies are developed for the entire company. Also, exchanging information and experience among the construction project teams accelerates distribution of new technologies. Second, developing new technologies rapidly in one project contributes to the rapid technology development for the entire company. Third, in order to achieve evolvability, the construction project team needs to share their needs in the site and feedback of the technologies

actively with the external stakeholders such as the headquarters and suppliers instead of just doing passively what the headquarters and supplies propose. Finally, the team can respond to the change in the ecosystem by collecting information from the external stakeholders constantly. Additionally, willingness to change the conventional ways and try new ways is a desired cultural aspect to achieve adaptability.

In order to realize the company's goal, a close collaboration between the headquarters and the project team is indispensable. Figure 16 shows the desired future state from the viewpoint of collaboration inside the company.

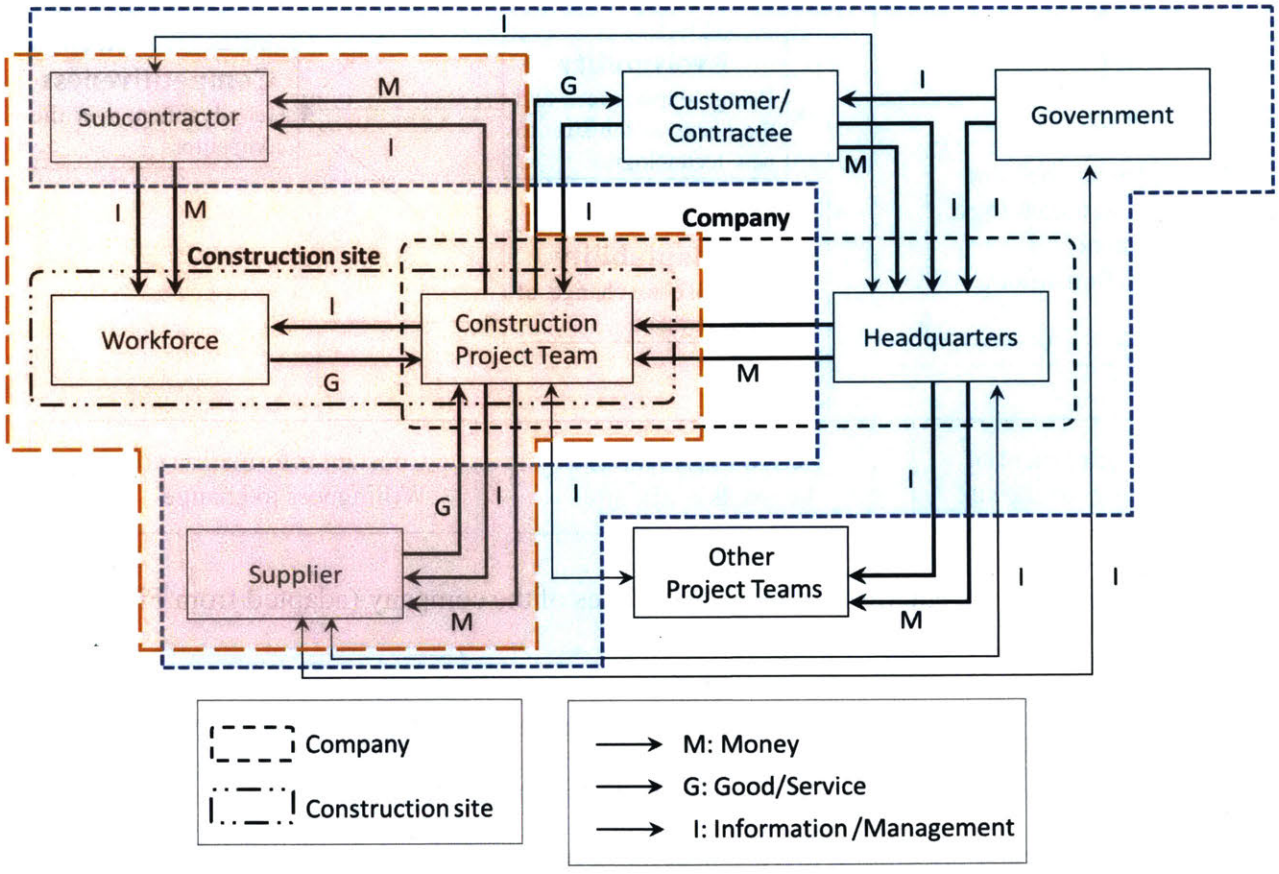


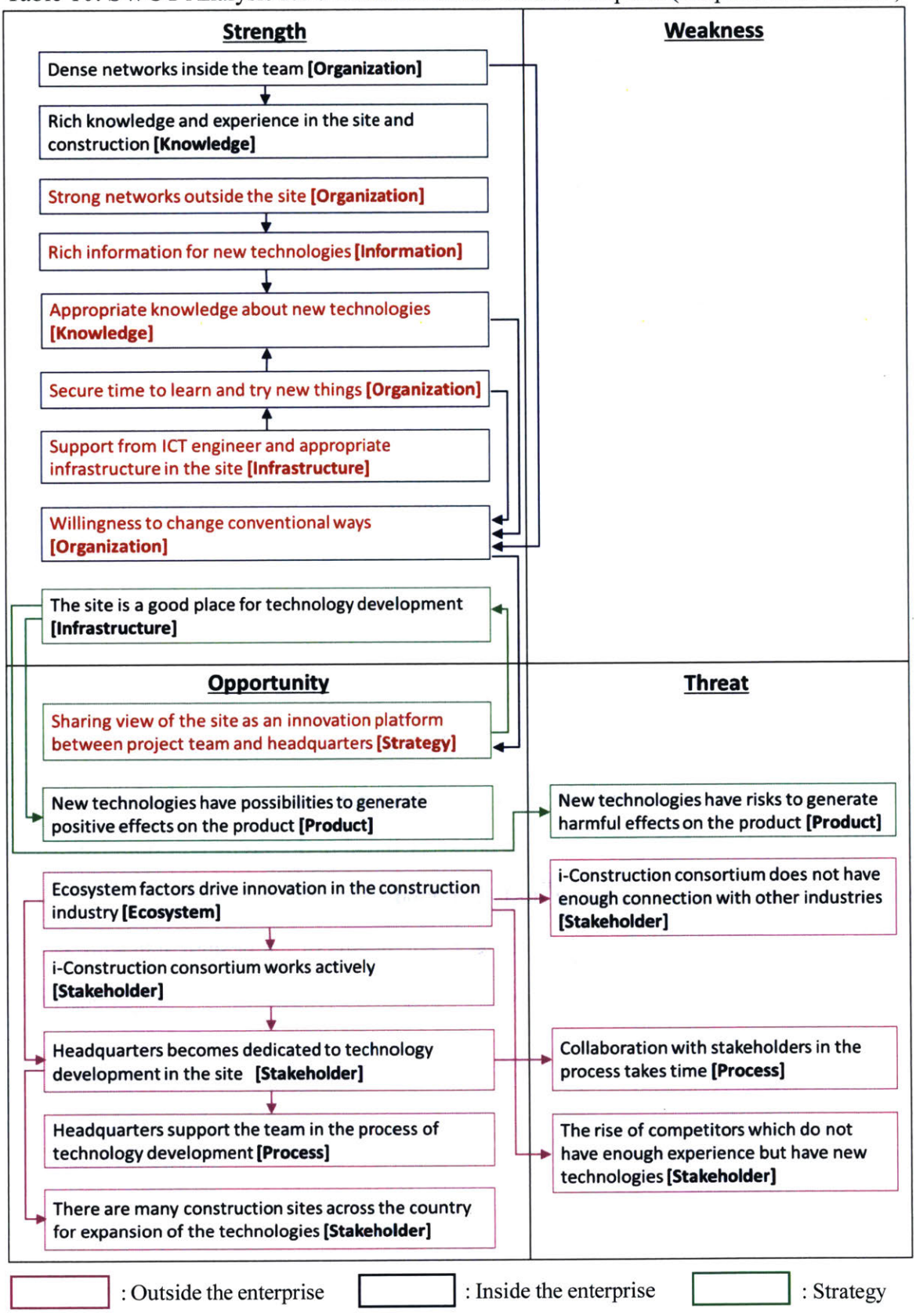
Figure 16: Desired future state as a company (adapted from Figure 7)

As described repeatedly in previous sections, the headquarters started to promote, introduce and develop new technologies in the site in reaction to the change in the surrounding ecosystem, which is shown by the blue arrow in Figure 16. On the other hand, the construction project team has not worked actively on technology development due to several factors as described in section 3.4. However, active involvement of the construction project team is important for technology development in that the team is the only component in the company which can capture the needs of the construction site adequately. The team has the potential not only to improve technologies introduced by the headquarters but also to develop new technologies by themselves collaborating with the stakeholders around the team such as suppliers, subcontractors, and workforce, as the orange arrow in Figure 16 shows. This interaction between the project team and the headquarters contributes to functioning better and achieving competitive advantages as a company.

3.5.2. Element-Based Details for the Envisioned Future

While the previous section focuses on the capabilities and desired states of the entire company, this section focuses more on the enterprise itself from the perspective of ten elements. Based on the result of SWOT analysis in Table 9, the desired states are shown in Table 10. The red colored factors have been shifted from the weakness or threat to the strength or opportunity. Since the factors listed in the threats cannot be shifted to opportunity only by the enterprise, most of the shifted factors were listed as weakness in Table 9. The details of the desired states are described based on the groups shown in Table 10: inside the enterprise, strategy, and outside the organization.

Table 10: SWOT Analysis for envisioned future of the enterprise (adapted from Table 9)



- Inside the enterprise

One of the important factors for envisioned future is the relationship with the external stakeholders, especially the suppliers. Currently, although the construction project team has connections with the suppliers related to construction industries, the team does not have enough relationships with the cutting-edge technology suppliers from different domains such as robotics, IoT, and AI. If the team builds relationships with those suppliers, the team can collect sufficient information for the technologies, which leads to gaining more knowledge about them. Additionally, this relationship has a positive impact on the suppliers in that they can get more opportunities to see and understand the actual situation of the construction sites such as the needs of the construction sites and the current methods and technologies. This information helps the suppliers understand which of their technologies can be leveraged and how the technologies can replace with or connect with the current technologies in the site. Therefore, the rich experience in the construction site and knowledge about cutting-edge technologies can be well integrated into new technologies. Another important factor is ICT-friendly infrastructure, where ICT software such as 3D CAD and SIM is provided to the team. More opportunities to use ICT software allow the team to learn it and acknowledge the value. In addition to distribution of software, easy access to ICT engineers helps the project team learn new technologies efficiently and reduce time to master them. These factors mentioned above enhance the willingness to change the conventional ways and try new things.

- Strategy

The construction site is a beneficial place in that new technologies can be applied to the real environment instead of the research institute. However, currently, the construction project team tends to be reluctant to introduce new technologies because their goal is to complete the project without troubles rather than try and develop new technologies from long time perspective which is same as the headquarters. In contradiction to the current status, the desired situation is

that the construction project team sets technology development for future projects as another goal of the project. The consistency of the strategy between the project team and the headquarters accelerates effective utilization of the construction site for developing new technologies.

- Outside the enterprise

The factors included in the group named outside the enterprise are difficult to be changed easily only by the enterprise. Rather than that, they are strongly affected by the ecosystem. Therefore, these factors are not focused much in this research.

3.5.3. Evaluation Criteria

The evaluation criteria for selecting a preferred future architecture are created based on the holistic vision described above. As Table 11 shows, eight of the criteria are the capabilities of the enterprise which contribute to achievement of the company's desired capabilities. In addition, risk and transformability are set as additional criteria in that it is necessary to evaluate whether the transformation to the new architecture is feasible or not.

Table 11: Evaluation criteria

Capability of the company	Criteria (Capability of the enterprise)	
Agility	Knowledgeability	Knowledge and experience in new technolgies [Knowledge]
	Learnability	Infrastructure for learning and trying new technologies [Infrastructure]
	Consistency	Sharing view of the site as an innovation platform [Strategy]
Adaptability	Accessibility	Constant information gathering [Information]
	Flexibility	Willingness to change [Organization]
Evolvability	Evolvability	Active involvement in conveying the need of the site and feedback [Organization]
Replicability	Scalability	Number of the project teams involving in technology development [Stakeholder]
	Interoperability	Collaboration among the project teams [Stakeholder]
	Risk and transformability	

3.6. Summary

In this chapter, after the enterprise is defined as a construction project team at the beginning, the current architecture of the enterprise is analyzed from the viewpoint of ten elements including ecosystem and stakeholder. While many factors in the external landscape are driving technological development in the construction project sites, the internal architecture of the project team possesses several resisting factors, some of which are caused by the insufficient relationships with stakeholders. Based on the current state, the holistic vision is created by considering how the enterprise contributes to the achievement of the company's desired capabilities.

Chapter 4: Case Study

4.1. Case Study Overview

As described in Section 2.5, case studies are selected in different industries rather than construction industry in order to remove the stereotypes of the construction industry and generate novel ideas for alternative architectures. The case studies consist of two parts: field visit and interview, and literature review as shown in Table 12.

Table 12: Case study overview

Case study type	Company name	Company type
Field visit and interview	Company A	Supplier of automated mobile system
	Company B	Manufacturing company using the automated mobile system
	Company C	Logistics company using the automated mobile system
Literature Review	InnoCentive, Inc.	Open Innovation and crowdsoursing

First, three companies in the logistics industry were selected for field visit and interview in that it is similar to the construction industry in some ways. First, the logistics industry is dedicated to introducing cutting-edge technologies into the fields. Also, the distribution centers are separated from the headquarters and the resisting forces are likely to be generated. In this research, the field visit and interviews were performed in both the supplier which provides leading-edge technologies and the user companies which actually use the technologies in the fields so that different perspectives about introducing new technologies can be captured as shown in Figure 17. As for user companies, interviews were performed with both the distribution center manager and the technology innovation team manager at the headquarters so that the perspectives of both sides can be captured. In addition to the field visit and interviews, brief brainstorming about alternative architectures of the enterprise was also performed with the interviewee, which provided beneficial insights for generating novel concepts.

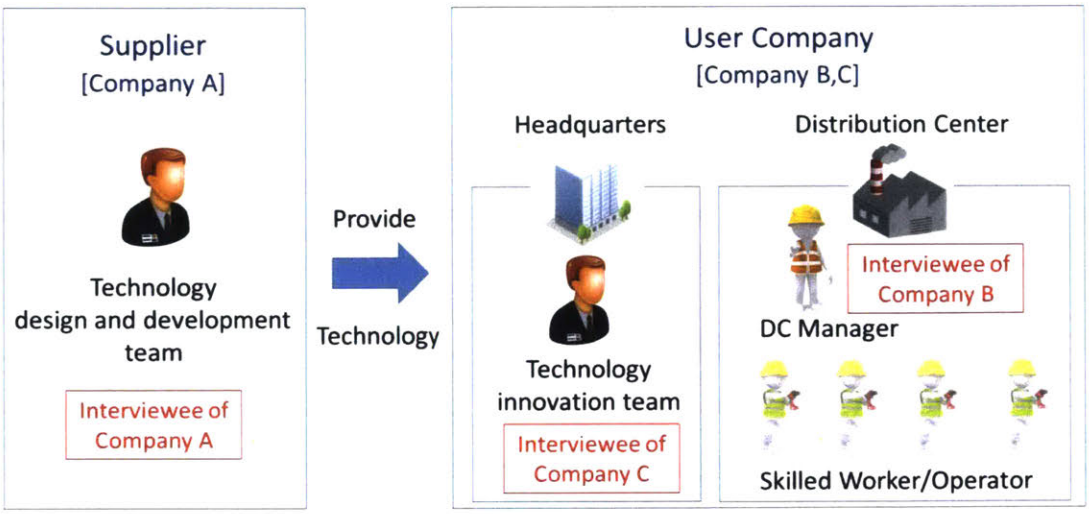


Figure 17: Schematic overview of the field visit and interview

Second, literature review about an innovation platform was conducted in that one of the current challenges the construction project team has is the weak relationships with the leading-edge technology suppliers. The analysis of InnoCentive platform provided insights about how to connect two entities with keeping high incentives to participate in the platform.

4.2. Case 1: Leading-edge Technology Supplier (Company A)

A case study about a leading-edge technology supplier was performed in order to capture the actual situations about introducing new technologies into the sites from the perspective of suppliers. The name of the company is not put on this thesis for the purpose of the protection of the anonymity of the company. An interview with an employee was performed, followed by a brainstorming session with the interviewee.

4.2.1. Company Overview

The company, hereinafter this is called "Company A", is an American robotics and technology company based out of the Greater Boston area. Company A has developed automation technologies and supplied autonomous mobile systems to manufacturing plant and distribution centers in the supply chain industry.

4.2.2. Interview

The interviewee is a business development and solutions design manager in Company A. Questions are related to the relationships with the logistics companies as customer and the countermeasures for the potential challenges when introducing new technologies.

- Relationships with the logistics companies

The contact persons with whom Company A communicates when introducing the technologies generally depend on the degree of maturity of the technologies. In the early stage, Company A usually works with the special team for technology innovation in the headquarters of the logistics company so that the headquarters can understand the technology and consider which distribution center is appropriate for the first adopter as a pilot test. This stage takes around 6-12 months depending on the risk appetite and allocated budget of the logistics company. After the pilot test is succeeded and the value of the technology is acknowledged in the logistics company, the stakeholders with whom Company A communicates change gradually from the headquarters to the warehouse managers at individual facilities, as well as expanding their contacts at headquarters to the operations, facilities, procurement, and/or IT teams at large, rather than working exclusively with the corporate innovation team. (e.g. the individuals, teams, departments and divisions responsible for designing and managing warehouses in the company's network and whom will ultimately solicit vendors and purchase technologies for "standard" warehouses as opposed to pilot sites).

- Countermeasures for the potential challenges

Company A has several countermeasures for the potential challenges when introducing new technologies. First of all, considering that the skilled workers have concern they may lose jobs when the autonomous mobile system is introduced, Company A puts an emphasis on improving productivity and safety of their jobs instead of replacing them. In addition, Company A provides different training programs about new technologies depending on the positions. For

example, while the training for the skilled workers mainly consist of how to operate the autonomous mobile system, the training for the warehouse managers consists of how the technology works so that they can best understand how to utilize and optimize it going forward; the operational benefits of the solution (via administrative dashboards and performance reporting); how to educate new operators; as well as how to operate and maintain the system.

4.2.3. Brainstorming with Supplier

Discussing with several people is more effective than thinking alone when generating alternative architectures. As such, a brainstorming session was performed with the interviewee of Company A. After sharing the context of the research, the analysis of current architecture, and envisioned future with the interviewee briefly, the interviewee and the author performed a brainstorming about how to introduce new technologies into the construction sites smoothly by referring to the cases in the logistics industry. Based on the case of Company A, the idea of collaborating with different stakeholders depending on the maturity of the new technologies was generated, which consists of three types. First, when the technology has not been matured yet, a special team in the headquarters needs to work closely with the suppliers to understand the technologies and decide the fields to which the technology is applied. Second, once the project to which the technology is introduced is decided, a pilot experiment jointly offered by the headquarters and the construction project team is conducted in the construction sites. It is key to receive prior buy-in from top management of the construction project team and to nominate one of them as a "champion" for the pilot technology to encourage buy-in from the rest of the project team as the pilot plays out, as otherwise the project team can feel like they are simply performing an "experiment" for the headquarters and will assume the technology is not going to be seriously adopted and/or impact their day-to-day activities at the end of the pilot period. It is also key to understand the limitations of the current state of the technology, but also not to design the pilot experiment in such a limited way that it forces such excessive constraints on the supplier and/or the pilot site project team that it does not mimic a production-ready solution, as this will likely

require follow-on pilots to demonstrate the benefits it can bring and further delays both project team buy-in and technology adoption rates in general. Company A said both of these scenarios are very common in large, conservative companies and can be one of the largest hurdles to overcome. Finally, after completing the pilot experiment, assuming the project was successful and the technology demonstrated tangible benefits that are desirable for future adoption, the pilot site should take the initiative to invite the other construction project teams to the site where the technology is demonstrated and the involved construction project team shares the experience of using the newly introduced technology with the other teams, which enables them to acknowledge the value of the new technology without feeling pressured from the headquarters. This also demonstrates further commitment on the part of the pilot site that they are willing to take ongoing responsibility for adopting and maintaining the technology. Finally, the other construction project teams start to connect and collaborate with the supplier in order to introduce the technology into their project sites.

4.2.4. Insight

Through the interview and brainstorming with the manager in the supplier, taking into account the supplier's perspective is crucial when creating future architecture of the enterprise. While it is beneficial for people working in the sites to build connection with cutting-edge technology suppliers, it is important for the suppliers to have relationships with the headquarters as well as the sites in that the suppliers have different needs depending on the maturity of the technology, which is regarded as TRL, Technology Readiness Level [28]. The needs of the suppliers are composed of several levels in terms of the maturity: developing new technologies, examining prototypes in actual fields, introducing and expanding the matured technologies to many fields. Although the suppliers work with project teams when they are inclined to introduce the matured technologies, they may want to collaborate with the headquarters in the early stage of the technology. In light of different needs of the suppliers, one potential future architecture would

enable the suppliers to communicate easily with both the headquarters and the construction project team rather than connect with only the project teams.

4.3. Case 2: Distribution Center (Company B) Using the Leading-edge Technology Supplied from Company A

4.3.1. Company Overview

Company B is a dealer authorized by a large machine maker which sells new and used earthmoving equipment. The company is a family-owned company and currently it has around 1,000 employees. Case study was performed in the largest distribution center of the company which introduced the automated mobile system developed by Company A.

4.3.2. Interview

The interviewee is a distribution center manager of Company B. Questions are related to the relationships with the leading-edge technology suppliers and the countermeasures for the potential challenges when introducing new technologies.

- Relationships with leading-edge technology suppliers

The owner of Company B started to promote technological innovation in the distribution centers several years ago in order to improve productivity and safety of the daily operation of the distribution centers. The managers of the distribution center generally collect information about new technologies by communicating with consultants and participating in conferences and trade shows. Actually, the managers built relationships with Company A in a large trade show five years ago.

- Process of introducing new technology and countermeasures for the potential challenges

Since the managers were concerned with the resisting forces from the skilled workers, the

managers held open dialogue sessions about introducing the automated mobile system in advance of actual introduction. Although some skilled workers made complains and concerns about it such as "We will lose our jobs" and "It is just waste of money", the managers said to them patiently that the new technology is just a tool to improve productivity and safety of their jobs rather than replacement for them. In addition to the open dialogue sessions, the managers had a demonstration event where the supplier, Company A, showed the new technology at the distribution center so that the skilled workers as well as the managers could understand how it worked and acknowledge the value of the new technology. The interviewee said that this event was a great opportunity in that the managers and the skilled workers communicated with the suppliers as well as saw the technology on site by their own eyes. Although there were some complaints after introducing the new mobile system, the skilled workers acknowledged the value of the new system gradually.

4.3.3. Facility Visit

A facility visit was conducted in order to see the performance of the new technology and grasp the working environment of the distribution center. First of all, the new technology is designed and managed in a user-friendly manner. The user interfaces such as operation screen and signal are easy to understand and operate without any expertise about automation technologies. Also, the skilled workers and managers can contact with the supplier whenever they have issues with the new system, and the supplier solves the issues immediately by remote control, resulting in successful operation without any critical problems. In addition to troubleshooting, the manager said that he is now collaborating with the supplier in updating the new system generated by the manager who is responsible for monitoring the performance of the system. This indicates that introducing new technology helps to create an environment where innovative ideas are generated more easily. Finally, as for the working environment of the distribution center, the relationship between the managers and the skilled workers is quite open. The author observed that one skilled worker made a suggestion to the manager about the equipment he was operating. This open environment plays an important role in mitigating resisting forces against introducing new

technologies.

4.3.4. Insight

This case study illustrates the importance of "Unfreezing" stage as Lewin pointed out [7], where the skilled workers as well as the managers understand the needs of change. In order to unfreeze successfully, an open environment achieved by daily close communication between the managers and the skilled workers is crucial. Additionally, the relationships between the user company and the supplier become tighten after introducing new technology through the follow-up activities such as careful troubleshooting and further collaboration in updates of the technology. Therefore, what is important is how to connect the user company with appropriate suppliers at the beginning.

4.4 Case 3: The Headquarters of the Company (Company C) Using the Leading-edge Technology Supplied from Company A

4.4.1. Company Overview

Company C is an American courier delivery services company. Same as Company B, some distribution centers of Company C introduced the automated mobile system developed by Company A. However, Company C is much larger than Company B in terms of number of employees.

4.4.2. Interview

The interviewee is a managing director in the operation technology innovation team at the headquarters. The team consists of around 70 members and is responsible for R&D and implementation for field operation of 40 ground shipping centers. Questions are related to the relationships with the leading-edge technology suppliers and the countermeasures for the potential challenges when introducing new technologies into the distribution centers from the perspective of the headquarters.

- Relationships with leading-edge technology suppliers

The technology innovation team usually collects information about new technologies by participating in the trade shows, and doing internet search based on the challenges provided by the distribution centers. After choosing some candidate suppliers for the solution, the team holds a competition where the candidate solutions were examined by a few distribution centers and evaluated based on the performance and cost to choose one solution.

- Process of introducing new technology and countermeasures for the potential challenges

The interviewee mentioned that the resisting forces come from both the distribution center managers and the skilled workers. Also, he pointed out that the size of the resisting forces is different among the distribution centers and it depends on the culture created by the distribution center managers. Considering the above, the technology innovation team puts an emphasis on getting buy-in from the leadership team of the distribution center at the beginning in order to create a positive environment for technology development across the distribution center. In addition, the team places importance on training for both the managers and the skilled workers when introducing new technologies. The interviewee mentioned that introducing new technologies do not always reduce the resisting forces against new technologies, but rather it depends on the actual performance of the introduced technology. When the new technologies do not work well, the team takes initiative to collect feedbacks from the users and improve them as soon as possible to earn the trust from the users. As for the process of expanding new technologies company-wide, the team usually performs pilot experiments in a few distribution centers to make sure the performance of the new technologies before company-wide distribution.

4.4.3. Insight

The important finding gained from this interview is that the involvement of the persons or teams creating the environment in the site is crucial for success in introducing new technologies into the site. As the technology innovation team of Company C puts an emphasis on persuading

the top leaderships, it is important to find out who is the key person and increase their incentives at the beginning, which makes the change easier. The key person would not be always the top leaderships, but rather it would be different from site to site or from industry to industry.

4.5. Case 4: InnoCentive

The company investigated through literature review is InnoCentive, an open innovation and crowdsourcing company founded in 2001. The company provides an open innovation platform which connects a global community of scientists with the client companies looking for solutions to the problems. The reason for choosing the company for case study is that the connecting mechanism the company has may be applied to alternative architectures for the enterprise. In other words, the mechanism may help to generate ideas about how to connect the construction project team with cutting-edge technology suppliers, which is the desired situation for the enterprise. In this case, what is especially focused is how InnoCentive achieves the active collaboration between the scientists and the client companies through stakeholder analysis.

4.5.1. Overview

There are two important stakeholders in the InnoCentive model of open innovation, "seeker" and "solver". Seekers are companies or institutes who have problems to be solved but do not have appropriate solutions. On the other hand, solvers are scientists and scientific organizations from a wide variety of disciplines and they are potential solution providers to the problems seekers have. In addition to a large number of solvers, which has reached into 400,000 [46], 65% of them hold PhD despite the fact that academic record and degree are not included in the requirement of solver [45]. Figure 18 briefly shows the process of InnoCentive platform. First of all, a seeker identifies a problem and formulates as a "Challenge" so that solvers from different backgrounds can understand it without deep expertise. The challenge is posted on InnoCentive platform anonymously as shown in Figure 19. As for solvers, they find an open challenge posted on the platform and register to see the details. If solvers succeed in developing solutions, they submit the

solutions to the platform. After the deadline, a seeker evaluates the solutions solvers submitted and select those to award. Then, InnoCentive pays award to the solvers and transfers IP to the seeker. Finally, a seeker receives the contact detail of the awarded solvers for future communication [46] [47].

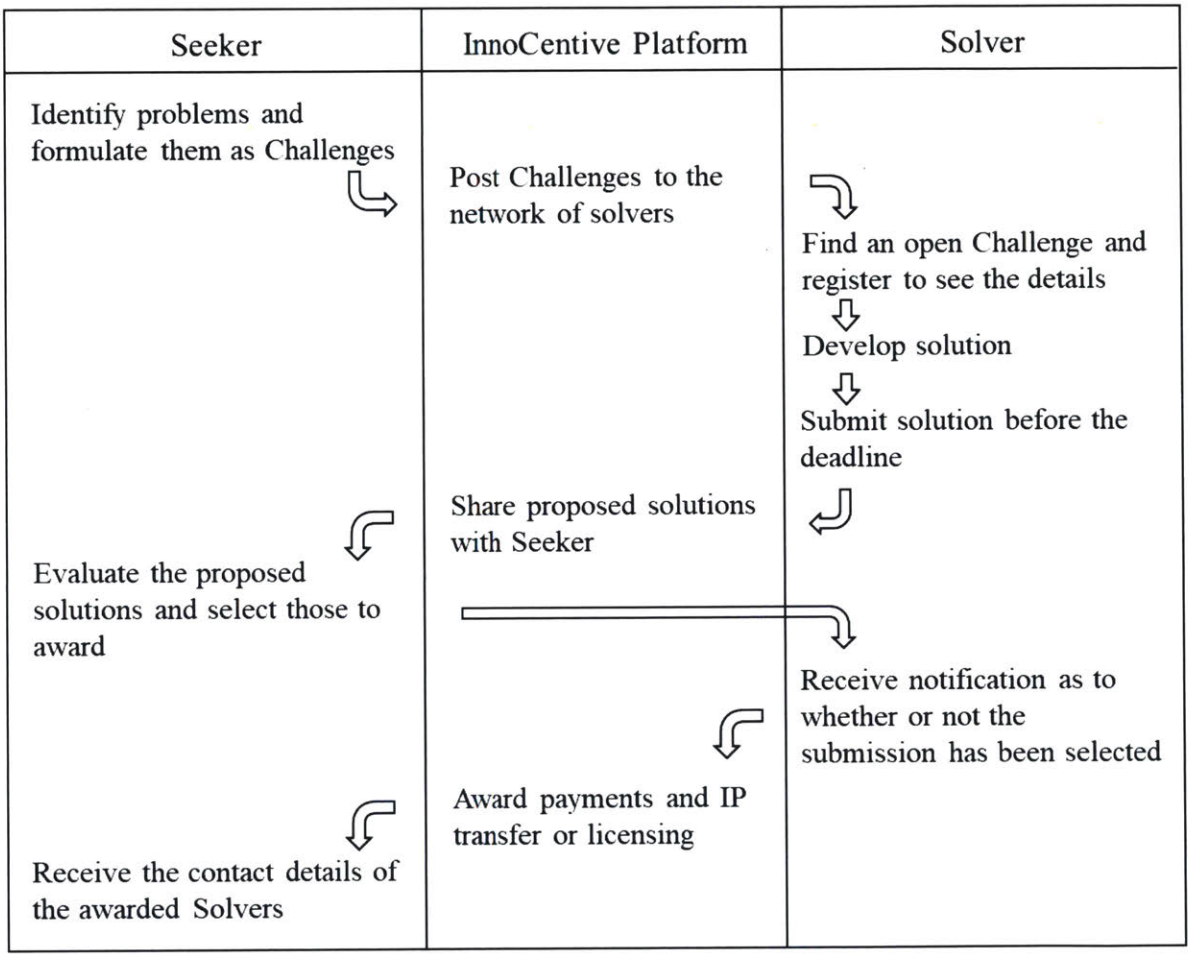


Figure 18: Process of the InnoCentive's service [46] [47]

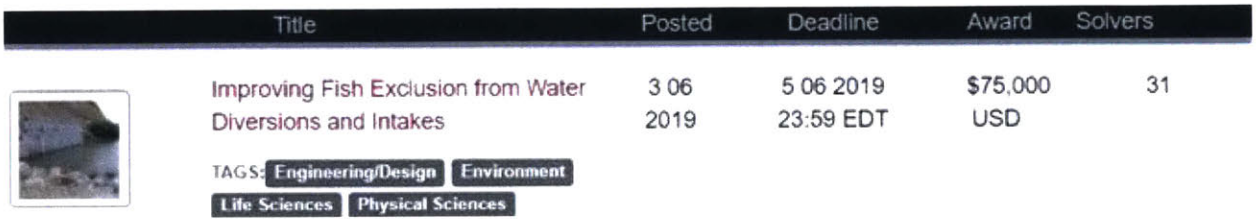


Figure 19: An example of challenge posted on the platform [48]

4.5.2. Architecture of InnoCentive

Stakeholder analysis is performed based on the process represented in Figure 18 to figure out how the InnoCentive model of open innovation works. Figure 20 is the stakeholder map of InnoCentive's service and it consists of four stakeholders: seeker, solver, InnoCentive, and InnoCentive platform. While InnoCentive shown in Figure 20 includes the employees of InnoCentive, the platform is shown outside of InnoCentive so that the difference between the platform and the employees can be shown clearly. As Figure 20 shows, InnoCentive collects registration fee only from seekers, not from solvers. Seekers receive trainings from InnoCentive employees about formulating challenges properly, which is important to get preferred solutions. In contradiction to seekers, solvers do not have direct relationships with InnoCentive employees. Instead, solvers exchange information and have relationships with seekers through the platform.

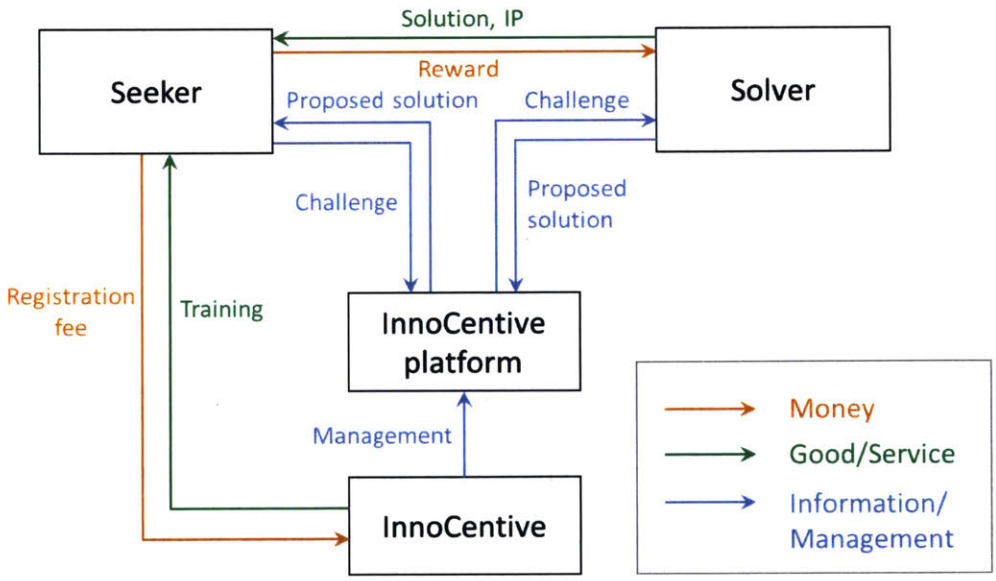


Figure 20: Stakeholder map of InnoCentive

Next, the incentives to use InnoCentive platform are discussed from the viewpoint of seekers and solvers.

- Seekers

The principal incentive for seekers to use InnoCentive platform is that they can get better, faster and cheaper solutions to the problems they currently have. First, seekers can get better solutions by reaching out to the quite broad pool of solvers from different backgrounds, countries, and experiences. Even in 2009, submissions were received from 10 solvers on average, which means that seekers were presented with results from 10 parallel experiments in problem solving at the same time [49]. Second, rapidly gain access to solutions enables seekers to get solution faster. There is no subsequent contract negotiations lasting months and stopping momentum after the conclusion of a challenge [50]. Third, seekers can get solutions cheaply by reducing labor cost for R&D. Although seekers need to pay $15,000 for registration fee and $10,000 to $100,000 for award [51], it may be cheaper than labor cost for research conducted inside the companies. In addition, the support from InnoCentive employees to formulate a challenge helps seekers get preferred solutions. Given the diversity of solvers, challenges need to be described in a manner that is general enough to attract a broad audience, but yet is specific enough that it provides enough information to actually get a solution [51]. Keeping this balance and creating attractive and proper challenges would be difficult without support from InnoCentive employees.

- Solvers

The biggest incentive for Solvers to join the platform is the reward for the solutions. Although the solutions are not always accepted, they do not have to pay any fees for using the platform. In addition to the monetary rewards, a Harvard Business School case of InnoCentive states that another incentive is intrinsic motivation, the challenge of solving puzzles and personal satisfaction that derived from tackling and devising solutions to difficult problems [49]. Malone also points out that motivation to participate in collective intelligence systems consists of glory, the desire to be recognized by peers for their contributions, as well as money and love [52]. Actually, the InnoCentive platform posts information about top solvers on the website who are

selected based on relative position in terms of both total winnings and the number of challenges awarded [53], which stimulates the intrinsic motivation of solvers. Also, the environment around researchers affects solver's incentives. Although the research outcome of the researchers is generally considered to belong to the company or research institute which they work for, labor laws set by several states in the US has presented a viewpoint that the research outcome achieved by using the personal time is not applicable to the contract. This drives researchers to join the InnoCentive platform for their own career development.

4.5.3. Insight

InnoCentive has established an effective innovation platform which meets the needs of both seekers and solvers, and provides them with high incentives to keep using the platform. When thinking about applying this platform system to the construction industry, seekers correspond to the construction project teams and solvers correspond to the leading-edge technology suppliers from different industries. Connecting the construction project teams and the suppliers is effective in that the teams need information about new technologies to apply to the construction sites and the suppliers are eager to introduce their technologies to construction industries to achieve a large market share. A concern is how to stimulate them and keep their motivations. The construction project teams are reluctant to change conventional ways. Also, the platform needs to be attractive to the suppliers compared with other opportunities. Therefore, one potential alternative architecture should have a well-designed mechanism that gives high incentives to participate in the platform to both the construction project teams and the suppliers.

4.6. Summary

Case studies of companies in different industries were performed to help to generate ideas about alternative architectures for the construction project team. Interviews were conducted in a leading-edge technology supplier and its user companies in order to capture the needs, the

stakeholder relationships, and the countermeasures for potential resisting forces in introducing new technologies from the perspective of both the supplier and the user company. The importance of taking into account the supplier's needs was recognized through the interview and brainstorming with the supplier. Also, an open working environment and on-site demonstrations play an important role in mitigating the resisting forces. In addition, involving the key person of the site and increasing their initiatives are crucial for the change. Besides the interviews and field visit, literature review was conducted in order to generate ideas about improving the relationships of the technology users with the suppliers. InnoCentive has a well-functioning platform which connects the seekers with the solvers by giving and maintaining high incentives to keep joining in the platform. The findings through the case studies will be leveraged in the following section, generating alternative architectures.

Chapter 5: Application of ARIES Framework II

This chapter describes the application of second half of ARIES framework which consists of generation of alternative architectures, deciding on future architecture, and developing implementation plan. The analysis of current architectures described in Chapter 3 and case studies in different industries in Chapter 4 are leveraged in the steps of this chapter.

5.1. Generation of Alternative Architectures

Generating alternative architectures is the fifth step of ARIES framework. It is important to generate concepts before diving into creating practical alternative architectures in that jumping directly to the solution is at the expense of failing to discover new possibilities [1]. In this section, several concepts are generated based on the previous steps, followed by convergence of the concepts into alternative architectures.

5.1.1. Generation of Concepts

Based on the envisioned future of the enterprise described in section 3.5, architectural concepts are generated as Table 13 shows, followed by the brief description of each concept.

Table 13: Concepts for alternative architectures

Concept	Description
Platform for connecting with suppliers [Stakeholder, Information, Knowledge]	Build connection between the construction project team and suppliers from different industries in order to collect information and gain knowledge about new technologies
Addional post for technology development in the team [Organiation, Information]	Assign additional employee to focus especially on technology development in the construction team
On-site events about new technologies from suppliers [Infrastructure, Information, Knowledge]	Hold on-site events such as demonstration of cutting edge technologies or pitch contest to expose new technologies to the construction project team

- Platform for connecting with suppliers [Stakeholder, Information, Knowledge]

One of the desired attributes of the enterprise's envisioned future is strong relationships with the external stakeholders, especially leading-edge technology suppliers from different industries in that the weak relationships with the suppliers result in the team's lack of knowledge and information about new technologies. Building platform enables the construction project team to connect directly with the suppliers, get familiar with new technologies they provide, and acknowledge the value of them. Direct connection with the construction project team is preferable for the suppliers in that they can capture the real needs of the construction sites.

- Additional staff for technology development in the team [Organization, Information]

From the perspective of organization and information, adding employees for technology development to the project team is effective because the project team does not have enough time to work on it currently. The additional employee should have knowledge about new technologies and connection with leading-edge technology suppliers so that the other team members can collect information and learn efficiently about new technologies from the additional staff.

- On-site events about new technologies from suppliers [Infrastructure, Information, Knowledge]

As mentioned in previous sections, construction sites are good places for examining and demonstrating new technologies in the actual conditions. The people working in the site including construction project team can acknowledge the value of the cutting-edge technologies as potential solutions to the problems through the on-site demonstration and pitch events.

5.1.2. Convergence of Concepts into Alternative Architectures

Alternative architectures are generated based on the concepts described in the previous section. As well as the stage of generating concepts, case studies performed in Chapter 4 are leveraged in generating alternative architectures.

- Architecture Option 1: Build a platform connecting the construction project team and the suppliers from different industries

First option is building a platform which directly connects the construction project team and the leading-edge technology suppliers from different industries based on the concept derived from InnoCentive platform. Figure 21 is the stakeholder map including the concept of this architecture option. Although the construction project team originally has relationships with suppliers related to construction industry, the alternative architecture has additional connection with the suppliers from different industries, which enables the project team to gain information and knowledge about new technologies from these suppliers without the headquarters.

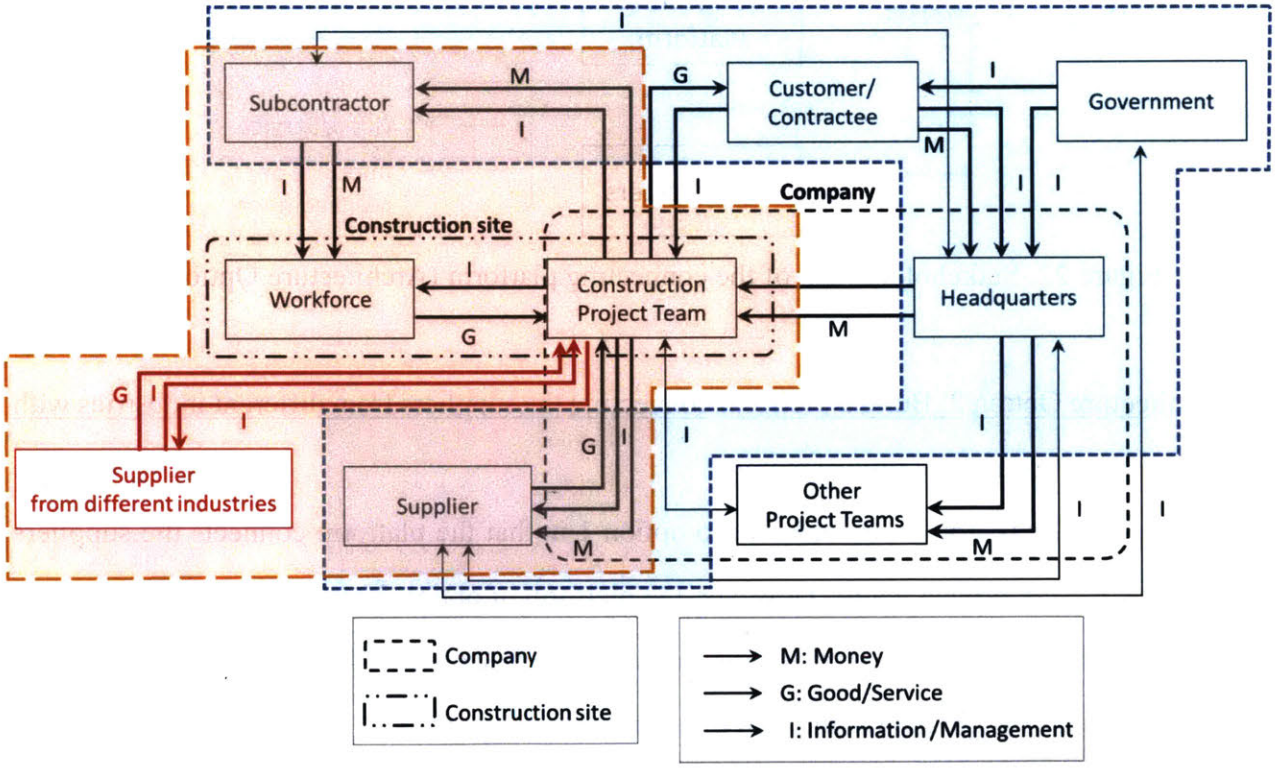


Figure 21: Stakeholder map of Architecture Option 1 (adapted from Figure 16)

Figure 22 shows the specific stakeholder map around the connecting platform. The function of the platform is similar to the InnoCentive platform. When the construction team has some issues in the site, the team posts the issues on the platform. Suppliers registered as solvers

can check the issues and post the solutions on the platform. Then, the construction project evaluates the solutions and selects those to award, followed by paying fee to the supplier for introducing the technology. The headquarters is involved in supporting the construction project teams for writing proper challenges as well as managing the connecting platform.

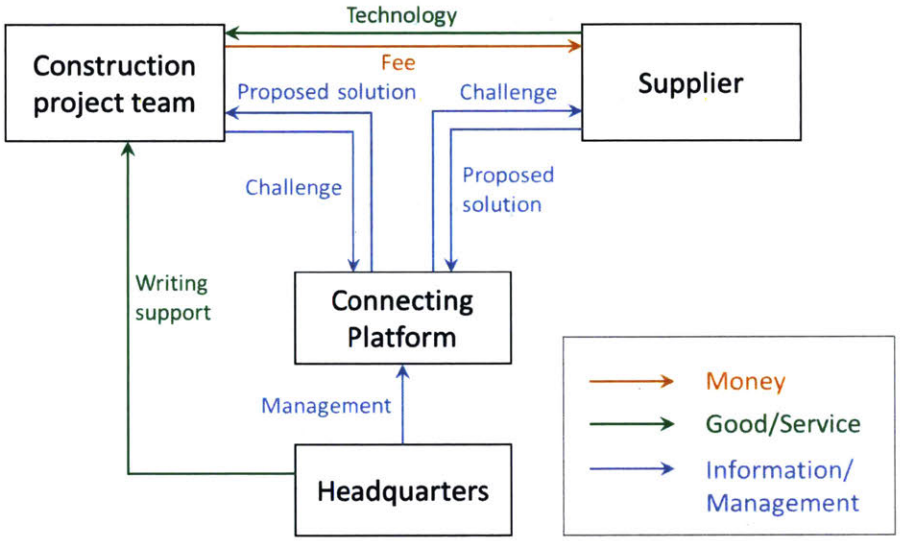


Figure 22: Stakeholder map of the connecting platform (Architecture Option 1)

- Architecture Option 2: Build a platform connecting the suppliers from different industries with the headquarters and the project teams

Option 2 has similar architecture to option 1 in that the platform connects the suppliers and the construction project teams. However, the platform of option 2 connects the suppliers with the headquarters as well as the construction project teams as shown in Figure 23. This architecture is derived from the insight gained through the case study of Company A, which is that the supplier may want to work with both the headquarters and the fields depending on the degree of maturity of the technologies. Consequently, the platform where the suppliers can be connected with both of them is preferable rather than the platform where they can be connected with only the field from the supplier's perspective.

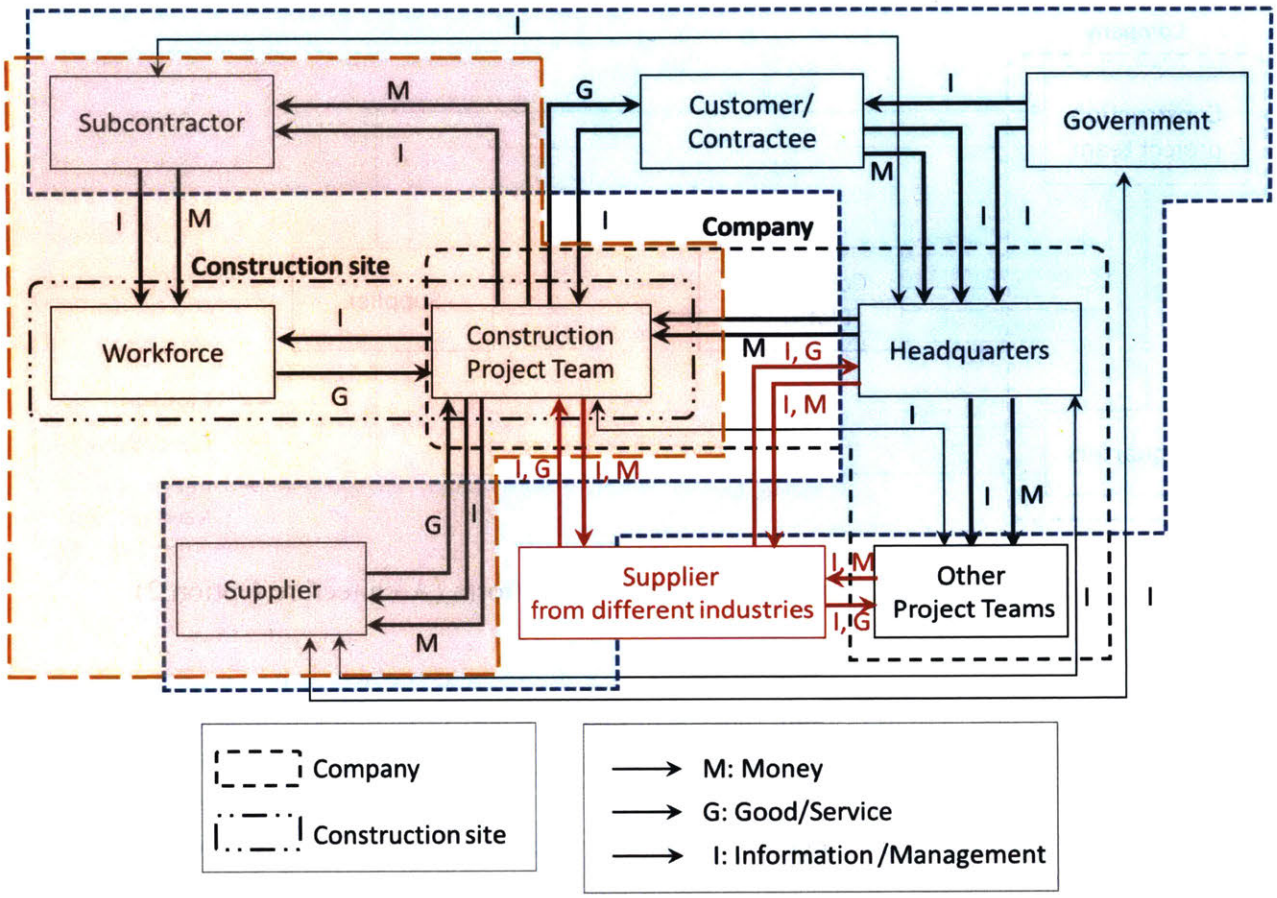


Figure 23: Stakeholder map of Architecture Option 2 (adapted from Figure 16)

Figure 24 shows the stakeholder map around the connecting platform of option 2. In contrast to the platform of option 1, the challenges are posted on the platform from the headquarters including research institute as well as the construction project teams, which means that the degree of maturity of the solution have diversity. While the construction project teams need relatively practical and matured technologies so that they can improve productivity using the technologies, the headquarters tends to seek technologies at the earlier stage for a long term view. Suppliers can post solutions selected from the diversified technologies in terms of the degree of maturity and build relationships with both the headquarters and the project teams on the same platform.

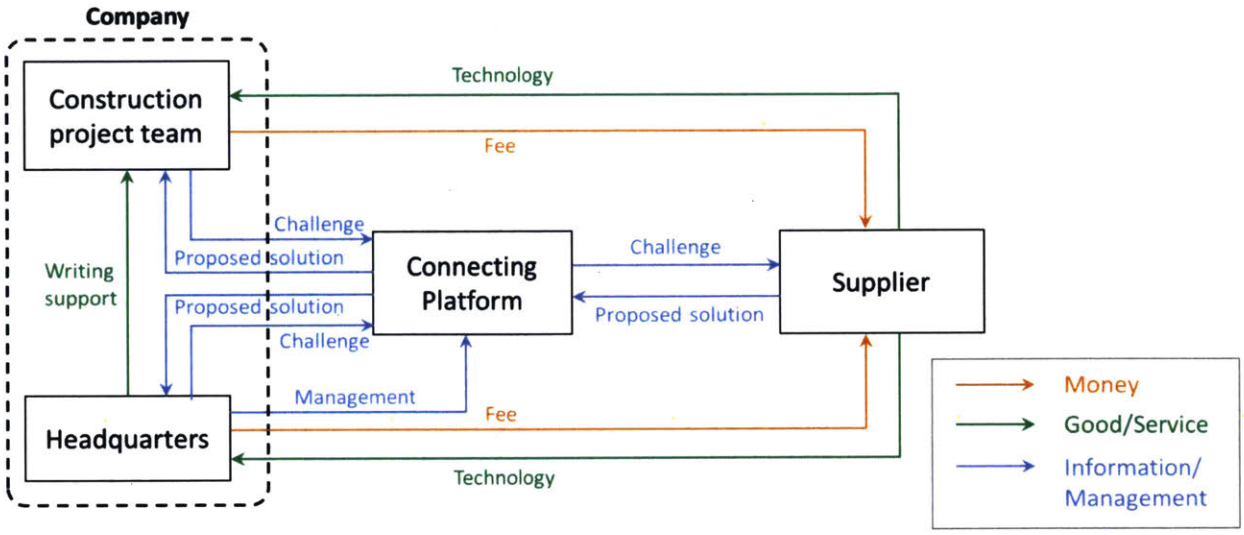


Figure 24: Stakeholder map of the connecting platform (Architecture Option 2)

- Architecture Option 3: Additional Staff for technological development in the construction project team

Option 3 embraces the change of internal architecture of the enterprise as shown in Figure 25. In light of lack of knowledge about new technologies and lack of time to try new things, adding staff who specializes in new technologies such as ICT and robotics is a reasonable option for alternative architecture. Since the additional staff has knowledge about new technologies and gain information constantly from the suppliers in different industries, the other staffs can gain information and learn new technologies from the additional staff instead of spending a lot of time doing by themselves as the red arrows in Figure 26 shows. Also, the additional staff can communicate with the headquarters about technology development in the construction site. Therefore, the additional staff works as the bridge between the construction project team and the external stakeholders.

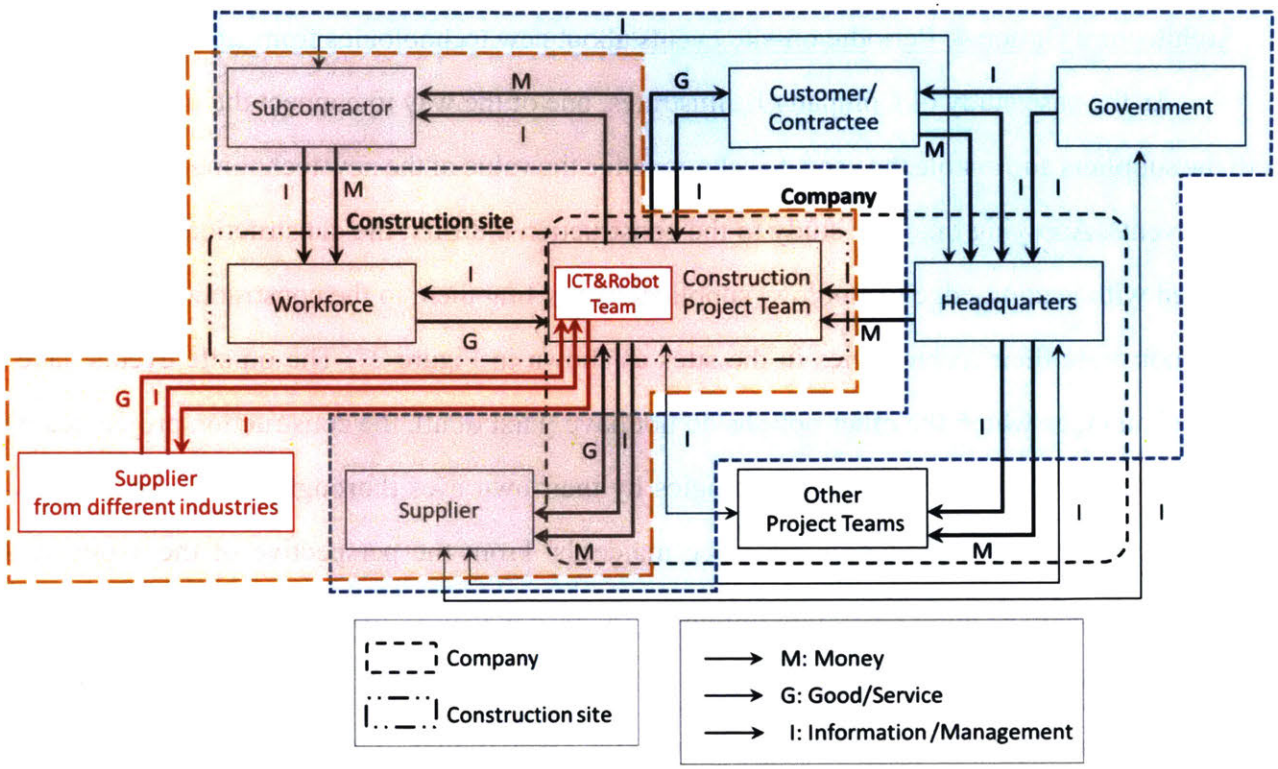


Figure 25: Stakeholder map of Architecture Option 3 (adapted from Figure 16)

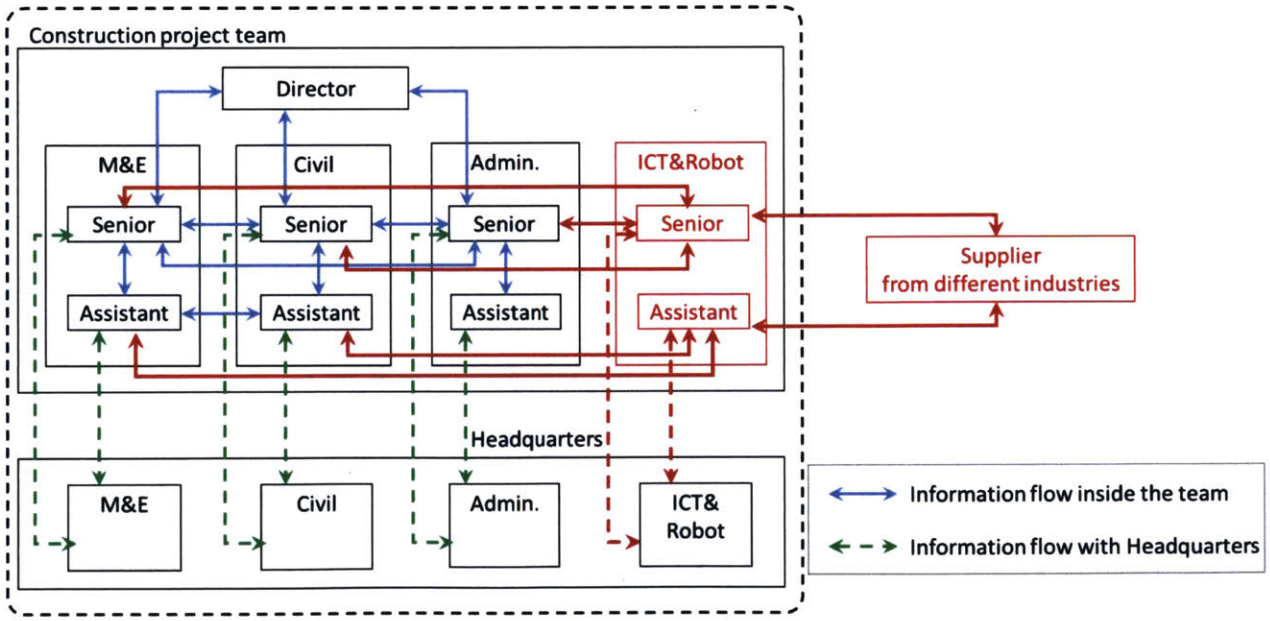


Figure 26: Stakeholder map of Architecture Option 3 (adapted from Figure 12)

- Architecture Option 4: Periodic on-site events about new technologies from suppliers

As the case study of Company B illustrates, one of the way to connect the user company with the suppliers and enable the users to acknowledge the value of the new technologies is holding on-site events. Applying this case study to the construction industry, the construction team can be connected with leading-edge technology suppliers by inviting them to the construction site where they demonstrate their technologies in the sites as shown in Figure 27. The on-site events have several advantages which the other options do not have. First of all, the construction project team can acknowledge the leading-edge technologies by their own eyes thorough the demonstrations instead of viewing the websites or reference materials. From the perspective of the suppliers, demonstrating their technologies is an attractive opportunity to let the actual users know them appropriately. Additionally, the suppliers have chances to get beneficial feedbacks from potential users and capture the real needs of the field sites which help to make the technology more useful. In spite of its temporality, having on-site demonstration events is effective in order to connect the construction project team and the suppliers closely.

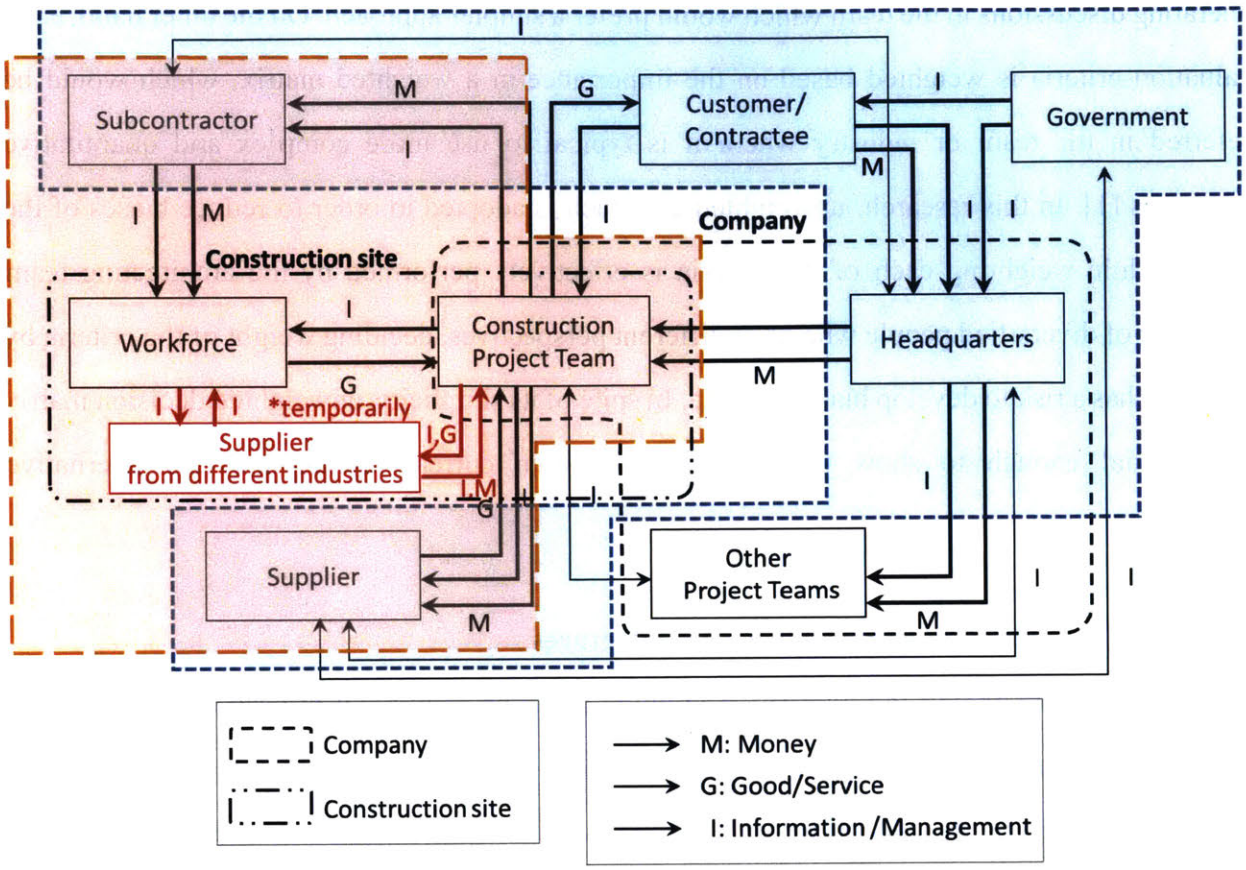


Figure 27: Stakeholder map of Architecture Option 4 (adapted from Figure 16)

5.2. Deciding on the Future Architecture

Deciding on the future architecture is the sixth step of ARIES framework. In this section, after the decision method is selected, one alternative architecture is chosen as a future architecture of the enterprise among the candidates discussed in section 5.1.2. Finally, future proofing is performed where the architecture is tested under different scenarios to examine its robustness.

5.2.1. Decision Method

Among many approaches for deciding on the future architectures, creating a decision matrix is an effective technique to compare alternative architectures. Decision matrices have two different variations: unweighted matrix, and weighted matrix. In an unweighted matrix, all of the evaluation criteria are considered to be equally important, which would be more effective

generating discussions in the team which would prefer a simpler approach. On the other hand, each evaluation criteria is weighted based on the importance in a weighted matrix, which would be preferred in the team or industry where it is typical to use more complex and quantitative techniques [1]. In this research, unweighted approach is adopted in order to reduce biases of the author. While weighting each of the criteria is effectively performed by the architecting team consisting of diversified people who have different perspectives, deciding weight of the criteria by the author has a risk to develop biased criteria. In spite of its simplicity, unweighted decision matrix is beneficial enough to show the difference between current architecture and alternative architectures.

5.2.2. Evaluation of Alternative Architectures

Before evaluating the alternative architectures, the evaluation criteria are reviewed in order to incorporate the insights gained through the case studies in Chapter 4. The original criteria were created based on the capabilities of the company and the enterprise. On the other hand, the importance of taking account of the supplier's perspective was acknowledged through the case study of the leading-edge technology supplier. In other words, when building the relationships with suppliers, it is crucial to enhance the supplier's willingness to join the networks with the enterprise and the headquarters. In light of this insight, a new criterion named connectivity from supplier's perspective is added to the evaluation criteria. This criterion means the ease of connecting with both with the construction project teams and the headquarters. In addition, considering that implementability consists of several factors, it was divided into four sub-criteria: time, cost, acceptability, and required training as shown in Table 14.

Table 14 is the unweighted decision matrix for evaluating alternative architectures. Each alternative architecture was evaluated against the current architecture as much better (+2), better (+1), same (0), worse (-1), or much worse (-2). While much of the literature uses only three levels: better (+1), same (0), worse (-1) for evaluation [54] [55], some literature uses five levels for rating

instead of three [56]. This analysis uses five levels in order to differentiate the size of the impact of each alternative architecture on each criterion. For some criteria, the sizes of the impacts are different from one architecture to another even though both of them have positive or negative impacts. The detailed evaluation of each alternative architecture is described below Table 14.

Table 14: Decision matrix for deciding on the future architecture

Evaluation Criteria				Current Architecture	Alternative architectures			
					[Option 1] Platform between team and suppliers	[Option 2] Platform between team, headquarters, and suppliers	[Option 3] Additional staff for technological development	[Option 4] Periodical on-site events from supliers
Criteria[1] Capability	Agility	Knowledgeability	Knowledge and experience in new technolgies [Knowledge]	0	+2	+2	+2	+1
		Learnability	Infrastructure for learning and trying new technologies [Infrastructure]	0	0	0	+1	0
		Consistency	Sharing view of the site as an innovation platform [Strategy]	0	0	0	0	+1
	Adaptability	Accessibility	Constant information gathering [Information]	0	+2	+2	+1	+1
		Flexibility	Willingness to change [Organization]	0	+1	+1	+1	+2
	Evolvability	Evolvability	Active involvement in conveying the need of the site and feedback [Organization]	0	+2	+2	+1	+1
	Replicability	Scalability	Number of the project teams involving in technology development [Stakeholder]	0	+2	+2	+2	+1
		Interoperability	Collaboration among the project teams [Stakeholder]	0	0	0	0	0
Criteria [2] Supplier		Connectivity	Esae of connecting with both construction project teams and headquarters	0	+1	+2	0	+1
Criteria [3] Implemantability		Time	Time to develop new architecture	0	-2	-2	-2	-1
		Cost	Cost for developing and maintaining new architecture	0	-1	-1	-2	0
		Acceptability	Enterprise's acceptability of new architecture	0	-1	-1	0	0
		Required Training	Required training associated with new architecture	0	-1	-1	0	0
		Σ +2		0	4	5	2	1
		Σ +1		0	2	1	4	6
		Σ 0		13	3	3	5	5
		Σ -1		0	3	3	0	1
		Σ -2		0	1	1	2	0
		Total Score		**0**	**+6**	**+7**	**+4**	**+7**

- Architecture Option 1: Build a platform connecting the construction project team and the suppliers from different industries

The connecting platform enables the construction project team to collect a lot of diversified information about new technologies constantly. Also, this ease of connecting with the suppliers enhances collaboration with them, which enables the team to accumulate knowledge and experience in cutting-edge technologies. As described in section 3.5, increase of information, knowledge and experience in new technologies will increase willingness to change conventional ways and try new things. Also, this option enhances evolvability in that the construction project team can convey the needs of the field directly to the suppliers without any agencies. As for scalability, the number of the project teams involving technology development will increase since every construction project team can join the platform. From the perspective of the suppliers, the ease of connecting with all of the construction project teams on the single platform is attractive. Finally, as for implementability, this option is relatively difficult to implement compared with the other options. The big challenge would be development time in that the company needs to design and develop the platform newly. Also, since the construction teams are not familiar with the online platform, some trainings for using the platform are required and there would be some resistance against using the platform from cultural perspective. On the other hand, once the platform is established, maintenance cost would not be so much high in that it can be updated and maintained online.

- Architecture Option 2: Build a platform connecting the suppliers from different industries with the headquarters and the project teams

The influence of option 2 on the capability of the construction project team is same as that of option 1 since the effects of the platform of option 2 on the construction project team are same as that of option 1. However, option 2 is more attractive to the suppliers in terms of ease of connecting with the entire company. While the suppliers need to connect with the headquarters in

different ways in case of option 1 whose platform does not include the headquarters, the suppliers can access to the headquarters on the same platform, which reduces their communication efforts. The implementability of option 2 is also same as that of option 1.

- Architecture Option 3: Additional staff for technological development in the construction project team

First of all, option 3 increases agility of the enterprise best of all of the options in that the additional staff will take the initiative to introduce ICT infrastructure into the project team and teach the team members how to use them directly as well as provide the knowledge and information about the new technologies. Although the staff can collect information about new technologies constantly, the amount of information is limited because it depends on individual networks with the suppliers. As for evolvability, although the additional staff can collect information about the needs of the construction sites from the other team members, the staff does not necessarily understand the needs appropriately since the staff is not familiar with construction projects. This option increases scalability in that the project team starts technology development in the sites once the additional staff joins in the team. Finally, option 3 has negative impacts on the implementability in that the employment cost for additional staff in every construction project team is high, as well as it takes time to recruit and educate the staffs.

- Architecture Option 4: Periodic on-site events about new technologies from suppliers

Although the construction project team can gain knowledge about new technologies through the on-site events, the knowledge is limited since the team can gain it only in the periodic events. However, demonstration of the new technologies on site enables the team to acknowledge the importance of introducing new technologies into the sites, which is consistent with the headquarters' strategy. As for adaptability, on-site demonstration is more convincing to the construction project team than just seeing information on website, which enhances willingness to

change the current way and introduce new technologies the best of all of the options. Evolvability is increased only a little due to the limitation of communication between the team and the suppliers. As for scalability, while the project teams that join the event are driven to start technology development in the sites, those which do not join are not driven. In terms of implementability, the on-site events are held easily compared with the other options in that the events do not need any specific infrastructure or new systems.

As pointed out by some researchers, it is dangerous to just focus on the total scores shown in the decision matrix due to its indistinct information available [57]. Therefore, the distribution of the score of each criterion is focused rather than the total score in this analysis. In terms of the capabilities of the company and the enterprise, option 1 and 2 have more positive impacts than the other two options in that they have more +2 criteria. In addition, option 2 has more positive impacts on connectivity from the supplier's perspective than option 1. However, option 2 has more negative impacts on factors related to implementability, which indicates that option 2 entails high risks as well as the possibility of high returns. On the other hand, option 4 has low risks in implementability while the positive impact on the capability is relatively small. Although it would be difficult to choose between the high-risk, high-return option and the low-risk, low-return option, these options can be integrated into one architecture considering the implementation plan. In other words, option 4 can mitigate the risks in implementability of option 2. As discussed above, designing and creating the connecting platform in option 2 takes time. Additionally, it is crucial to increase incentives of the construction project teams and the suppliers when the platform is actually launched. Taking account of these situations, the company can hold on-site events as suggested in option 4 while developing the platform, which drives the teams and the suppliers to participate in the platform to build relationships with each other as Figure 28 shows.

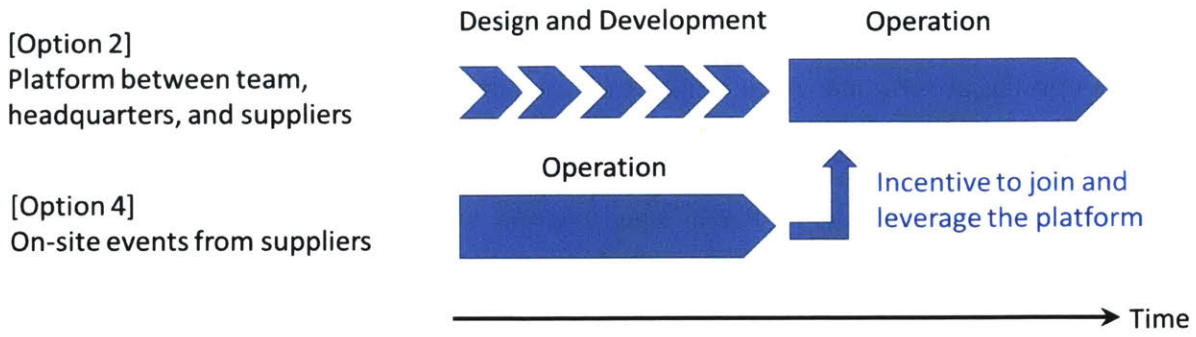


Figure 28: Brief concept of hybrid option derived from option 2 and 4

In light of the analysis and discussion above, the hybrid architecture derived from option 2 and 4 is selected as the best option for the future architecture. The details of the hybrid architecture will be described later in the section of implementation plan.

5.2.3. Future Proofing

Future proofing is an important process to check the robustness to the change of the ecosystem over time. The findings through future proofing will be leveraged in developing the detailed architecture. Three scenarios are created based on landscape analysis and each scenario is tested as follows.

- Scenario A: Decline in government's promotion of technology development in the construction industry [Politics]

Although Japanese government is currently promoting technology development in the construction industry, the government may decline the promotion in the future in light of successful cases accomplished in the next few years. However, it will not affect the future architecture so much since the platform is independent from government. Of course, in spite of the independence, establishing the platform and putting it on track before the government promotion starts to decline is crucial in terms of the sustainability of the future architecture

- Scenario B: Delay in revision of the standards for leading-edge technologies [Regulation]

Although the government is currently reviewing and revising the standards for coming technologies quickly, it may be assumed that the speed of technology development is much higher than that of revision of the standards. It will have negative impacts on the future architecture in that the incentives of both the construction project teams and suppliers to introduce new technologies will decrease. However, considering that the standards tend to be revised based on the actual performance of the technologies examined in the site, having many construction sites where new technologies are introduced may accelerate the speed of the revision of the standards.

- Scenario C: Decline in the economy of the construction industry [Economy/Market]

Currently, high demand for construction results in the increase of investment on technology development in the construction industry. However, it may be assumed that the demand will decrease in the future, which discourages the construction companies from investing in technology development. This will have negative impacts on the future architecture. In order to mitigate this impact, the company needs to develop technologies more quickly than the competitors to achieve competitive position. The future architecture increases the agility of technology development in that all of the construction project teams can start technology development at the same time without waiting for any agencies like the headquarters.

5.3. Implementation Plan

Developing the implementation plan is the seventh and final step of ARIES framework. This step plays an important role in making the future architecture more feasible. Before diving into developing implementation plan, validation of the future architecture is performed where the architecture's consistency with the strategic objectives and stakeholder values is assessed. Subsequently, the detailed architecture is developed based on the assessment above and discussions in selecting the future architecture. Finally, the implementation plan is described.

5.3.1. Validation of the Future Architecture

In this section, the selected future architecture of the enterprise is assessed from the perspectives of the capabilities of the company and the enterprise, stakeholder relationships, and ten elements. First of all, the alignment with the capabilities of the company and the enterprise have already been assessed in selecting the future architecture. Considering that the evaluation criteria are created based on the desired capabilities of the company and the enterprise, the future architecture is consistent with them as Table 14 shows.

Second, as for relationships with stakeholders, the selected architecture enables the construction project team to take the initiative to introduce and develop new technologies by collaborating with leading-edge technology suppliers as well as workforce and subcontractors as Figure 23 and Figure 28 shows, which results in achieving bottom-up approach to the company as shown in the envisioned future in Figure 16. In addition, Figure 29 represents the relationships between importance and performance of the stakeholders. While the black dots show the desired position shown in Figure 8, the red stars show the expected position in the selected architecture. Since the selected architecture is relatively independent from the customer and the government, it does not affect their performance. In contrast, the architecture increases the performance of the other stakeholders. Especially, it enhances the performance of the suppliers and the headquarters by connecting them with the construction project team on the platform. Although workforce does not join in the platform, it can collaborate with the construction project team and the suppliers at the on-site events.

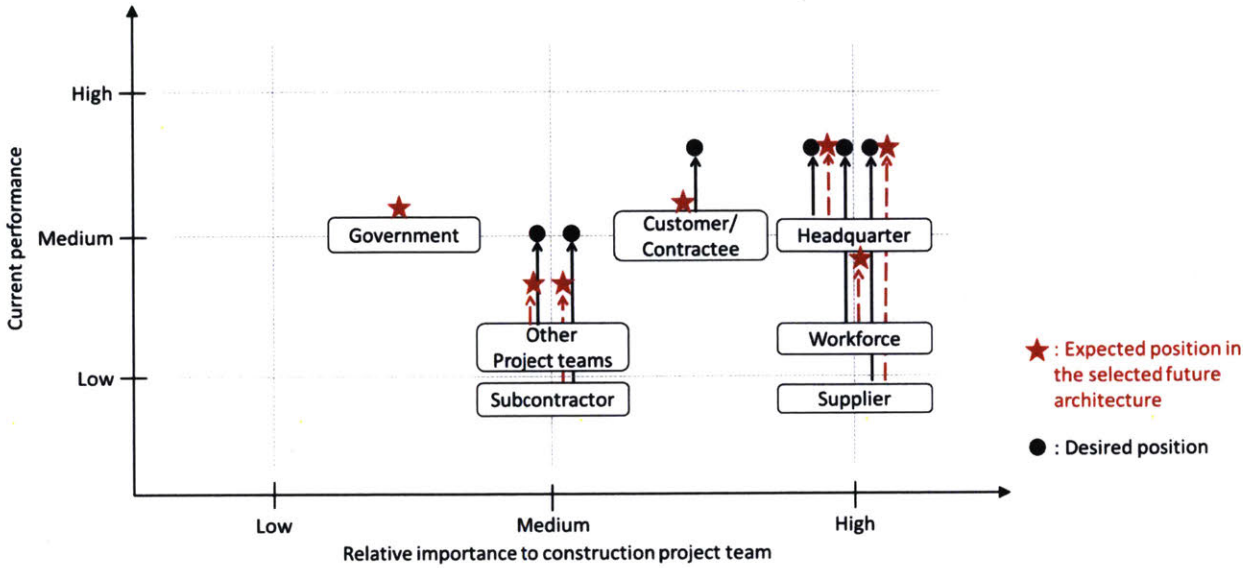
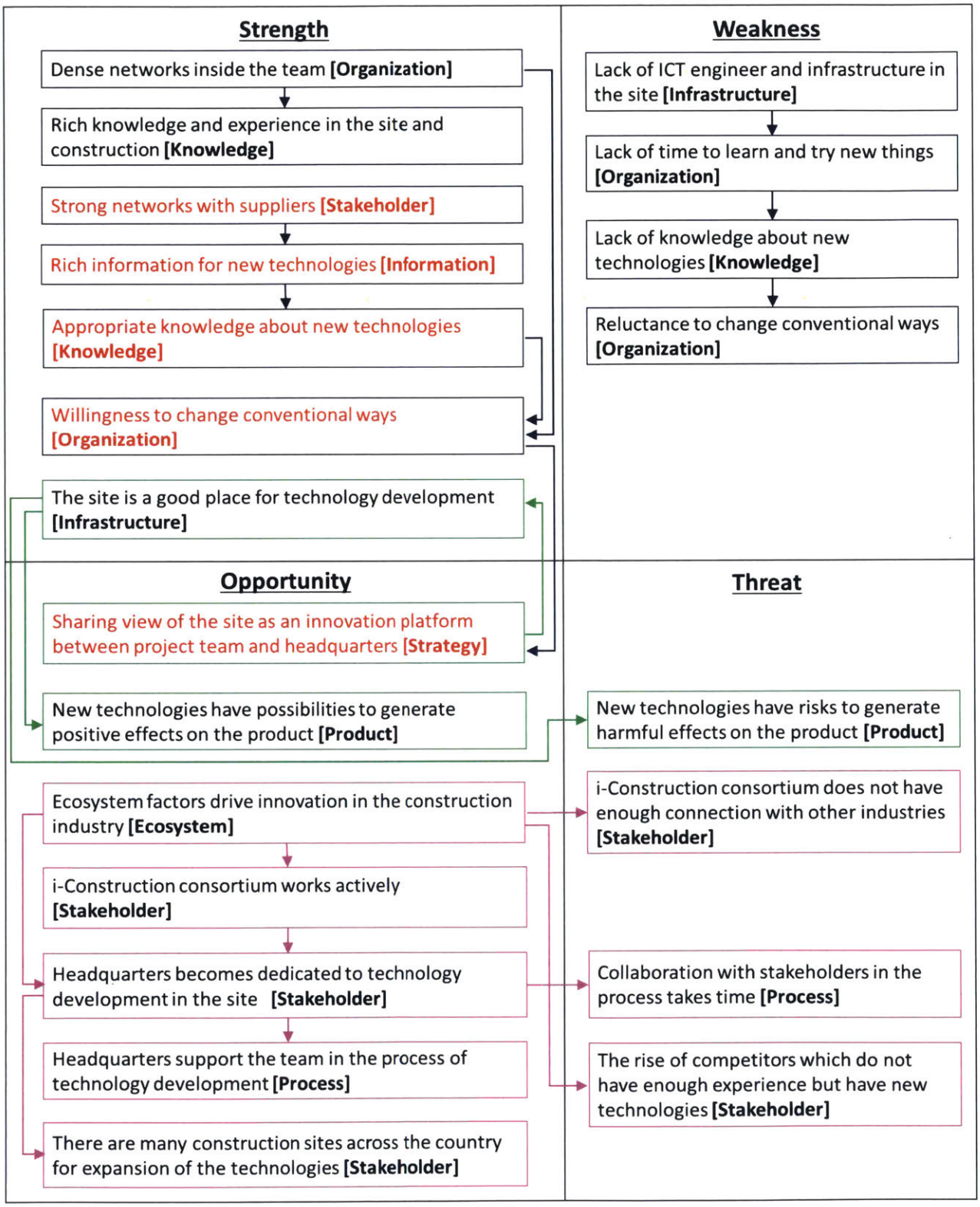


Figure 29: Relationship between importance and performance of stakeholders in the future architecture (adapted from Figure 8)

Third, the selected architecture is assessed from the perspective of ten elements. Table 15 shows the result of SWOT analysis for the architecture, which is based on Table 9, showing the result of current architecture. The red-letter factors in Table 15 are those moved from the negative area to the positive area by introducing new architecture. The connecting platform with the cutting-edge technology suppliers enables the construction project team to build relationships with them, gain information, and knowledge about new technologies from them. Also, on-site demonstration events are good opportunities for the team to realize that the sites are valuable places to test and introduce new technologies. In contrast, there are still some weakness factors caused by lack of ICT engineer and infrastructure in the site, which would be mitigated by alternative architecture option 3, additional staff for technological development. Some supplemental function to mitigate the weakness factors will be added to the selected architecture in the following section.

Table 15: SWOT analysis for selected future architecture (adapted from Table 9)



5.3.2. Detailed Architecture

As described in Section 5.2, the selected future architecture is a hybrid architecture consisting of on-site events about new technologies and an online platform connecting the leading-edge technology suppliers with the project teams and the headquarters. The details of the selected architecture are required to discuss in order to implement successfully. First, having on-site events plays an important role in increasing the incentives of the suppliers and the construction project teams to participate in the connecting platform during the design and development phase of the platform. Therefore, the events should be attractive to both the suppliers and the construction project teams. One of the specific events would be a technology demonstration event by the cutting-edge technology suppliers. This event is expected to increase the project team's motivation to collaborate with the suppliers by seeing the new technologies by themselves on site. Also, this is a good opportunity for the suppliers to display their technologies. Another specific event would be a technology competition for the construction site, which is analog version of the connecting platform. In this event, the leading-edge technology suppliers are invited to the construction site, where the construction project team makes a presentation about their needs and requirements for the new technologies. At a later date, the suppliers submit potential solutions and the project team choose one as the solution. This competition contributes to increasing the incentive of the suppliers to collaborate with the construction project teams. In addition, the feedbacks of the competitions can be leveraged to design the online platform.

Second, the details of the online connecting platform are discussed. Table 16 shows the potential risks of the connecting platform and the countermeasures for them, which are incorporated into the details of the platform.

Table 16: Potential risks of the connecting platform and the countermeasures

Potential Risk	Countermeasure
Fuzziness of the needs from seekers	- Set of three levels of needs: Practical, Experimental, Introductory
Low quality of the posted challenge	- Site visit and direct communication between seeker and solver before final submission of the solution
Low incentive of solvers	- Opportunity to particiate in on-site events - Posting successful solutions on the platform
Inactive collaboration among construction project teams	- Addition of communication function on the platform

- Potential risk 1: Fuzziness of the needs from seekers

From the seeker's perspective, the construction project teams and the headquarters need to clarify the needs of their challenges, especially the degree of maturity of the solution technology, so that the suppliers can submit appropriate solutions to them. Generally, the construction project teams tend to need practical technologies which are matured enough to be applied to the construction sites immediately while the headquarters tends to need more introductory technologies from a long-term standpoint. Based on the above, one possible countermeasures would be setting three levels of the technology maturity which the seekers need to choose when posting the challenge on the platform: practical, experimental, and introductory. First of all, the practical solutions are the most matured technologies solution which can be introduced to the construction sites without any major adjustment or further development. In terms of TRL, the levels of those solutions are 8 or 9 [58]. Second, the experimental solutions are those in a pilot phase, whose TRL is 5 to 7. Some construction project teams as well as the headquarters may be interested in the experimental solutions for near-future application to the sites. Finally, the introductory solutions are those in the early stage, whose TRL is 1 to 4. The headquarters including the research institute tends to be interested in the solutions of this level. This clear classification of the degree of maturity of the technology enables the suppliers to understand the needs of the seekers and propose appropriate potential solutions.

- Potential risk 2: Low quality of the posted challenge

In this context, low quality means that the challenge does not include enough information to understand the condition of the sites or specify the requirements of the solution, which leads to mismatch between the needs of the seekers and the solutions solvers provide. Actually, InnoCentive puts special emphasis on the quality of the posted challenges and assigns the staffs to provide trainings for the seekers on writing the appropriate challenges [51]. However, the construction company cannot do the same things as InnoCentive since there are few appropriate staffs in the company who have enough knowledge about new technologies to specify detailed requirements for the solutions. In light of the company's circumstance, a possible countermeasure for this risk would be providing the suppliers with an opportunity to visit the construction site before final submission of the solution, where the suppliers can see the situation of the site by their own eyes and communicate directly with the construction project team to clarify the questions about the challenges such as the requirements of the solution. This site visit is also beneficial to the construction project team in that the team can understand what the suppliers need for proposing the solutions, which is also useful when posting another challenge in the future.

- Potential risk 3: Low incentive of solvers

While the connecting platform is attractive to the construction project teams and the headquarters, it is not always attractive to the suppliers in that the platform connects the suppliers with only one company of all the construction companies. As such, it is important to give the suppliers high incentives to participate in the platform of the company. One of the countermeasures for this risk would be providing the opportunities to participate in on-site events to the registered suppliers of the platform. Joining the on-site events such as technology demonstration event is beneficial to the suppliers in that they can demonstrate the values of their technologies to the participant project teams, which are potential customers. Another countermeasure would be posting successful solutions on the platform same as InnoCentive does. Posting the supplier's name

and the technology on the platform plays an effective role in letting the other construction project teams and the headquarters recognize the supplier, which will lead to future collaborations with the other construction teams and the headquarters.

- Potential risk 4: Inactive collaboration among construction project teams

As show in Table 14, the selected architecture does not have any positive impacts on the interoperability, the ability to collaborate with the other project teams. Although this thesis focuses mainly on the connection between a construction project team and the leading-edge technology suppliers, collaborating among construction project teams such as sharing information and experience of new technologies is also important for achieving the company's strategic objectives. One possible way to enhance active collaboration among construction project teams would be communicating with each other on the platform. More specifically, the platform should have a function which allows the construction project teams to add comments on the post once a successful challenge is posted. This function enables the other project teams to hear the feedbacks about the new technologies from actual users, which will accelerate distribution of the successful technologies throughout the company.

Based on the discussion above, the details of the architecture are shown in the CONOPS, Concept of Operation, in Figure 30. CONOPS is a document describing the characteristics and intended usage of a proposed system from the viewpoint of its users. Its purpose is to communicate the system characteristics to all stakeholders and serve as a basis for stakeholder discussions about the system [59]. Each step of the entire process and the key attributes of the platform are described below.

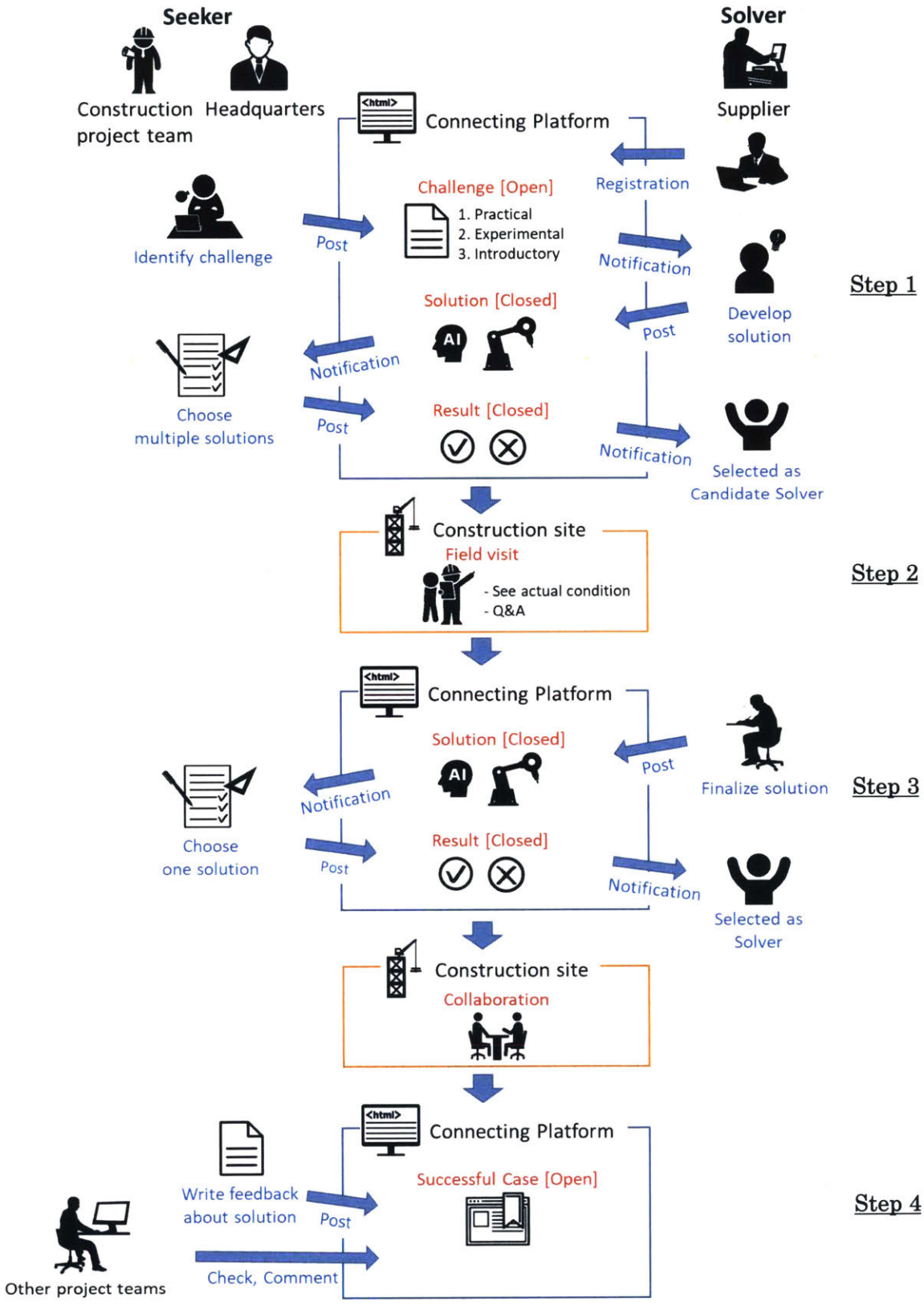


Figure 30: CONOPS for the connecting platform (image source: [60])

- Step 1: Post of challenge to Selection of candidate solvers

When the construction project team and the headquarters, hereafter they are called solvers, identify a challenge, they post it on the online platform where all of the registered suppliers can check it. Also, the degree of the maturity of the required technology is clearly stated in the posted challenge so that the suppliers, hereafter they are called solvers, can capture the seeker's needs. Once the solvers develop the solutions to the challenge, they post the solutions, which are open to only the seeker. Another key attribute of this step is choosing multiple solutions. Selecting one solution in this step is risky in that the solvers may not understand the seeker's needs fully and the seeker may not understand the solver's solution due to lack of knowledge.

- Step 2: Field Visit

This step enables the solvers and the seekers to understand each other. Through the field visit and Q&A session, the solvers can understand the actual condition of the construction site, the real needs of the seeker, and the requirements of the solution technology. Also, it is a good opportunity for the seeker to learn about new technologies from the solvers.

- Step 3: Finalization of solution to Selection of successful solver

After finalizing the solutions based on the field visit, the solvers post the solutions on the platform. The seeker evaluates the solutions and chooses one solution. If the seeker finds that no solutions meet the requirements, all of the posted solutions may be failed. The key attribute in this step is that the finalized solutions are open to only the seeker. After the seeker selects the solution, the seeker and the solver start collaboration and the solution technology is introduced into the construction site.

- Step 4: Post of successful cases

After the solution is selected, the selected solution is posted on the platform openly so

that the other seekers can see it, which is attractive to the solvers in that they get opportunities to distribute the successful technology to the other construction sites. In addition, the seeker adds the feedbacks of the solution technology after using it, which are open to the other seekers. This enhances communication and collaboration among construction project teams.

5.3.3. Implementation Plan

It takes time to develop the new architecture and transform to it. Also, from the perspective of change management, the implementation process is important for successful transformation. Figure 31 is the recommended implementation plan for new architecture, followed by the detailed description. As Figure 31 and the following description shows, the connecting platform and on-site events need to be interrelated with each other to implement transformation successfully.

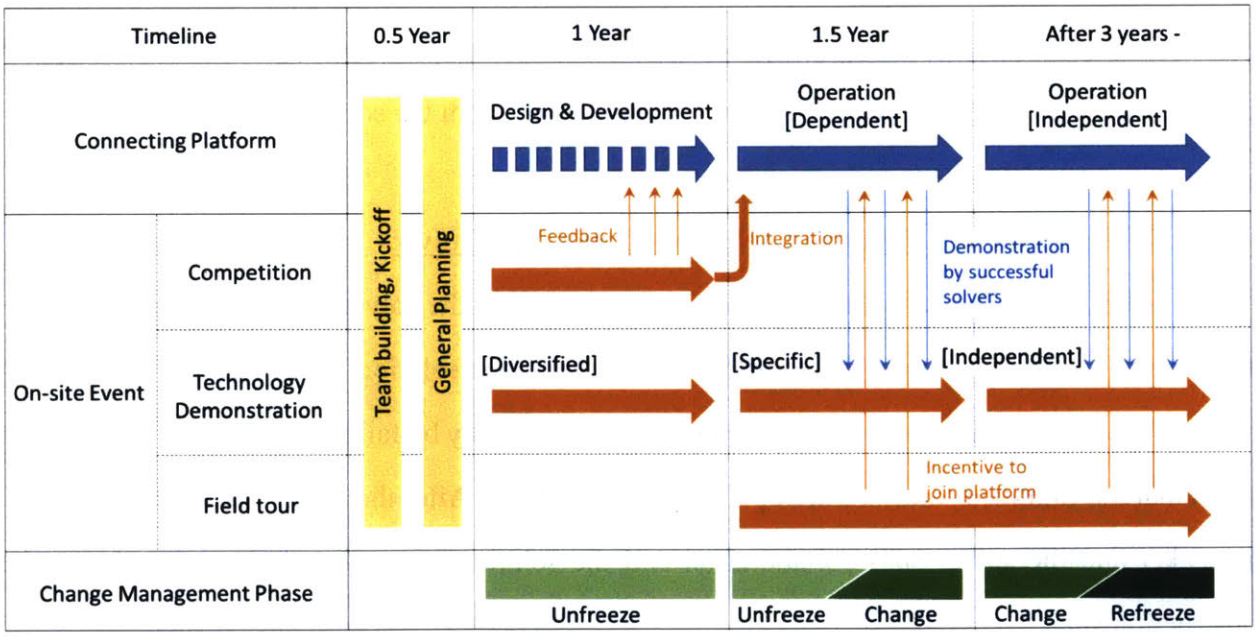


Figure 31: Implementation plan for the new architecture

- Project Kickoff (0.5 Year)

The special team for this transformation should be formed at the beginning of the transformation. In addition, the general planning about transformation is performed before the actual operations start.

- Design and Development of the connecting Platform (1 Year)

Although the connecting platform is in the design and development phase, this period is important in that the incentives of both the seekers and the solvers need to be increased through on-site events. Technology demonstration events are held in order to increase the motivation of the construction project teams to join in the platform and connect with the leading-edge technology suppliers. Since the construction project teams are not familiar with new technologies, the demonstrated technologies should be diversified, which enables them to recognize the potential values of the cutting-edge technologies. Another on-site event is a competition for the solution technology to the challenge in the site. In this competition, the construction project team presents the current issue in the site to the invited suppliers as well as the team takes them to the site tour. After the on-site event, the suppliers submit the potential solutions and the project team selects one solution technology among them. As this competition is an analog version of the connecting platform, the feedbacks of the competition can be applied to the design of the platform. As discussed above, this period is an unfreezing stage from the perspective of Lewin's change management model [7].

- Dependent Operation (1.5 Year)

The connecting platform starts operation in this phase. As John Kotter puts an emphasis on creating short term wins in the transformation process [11], the success of this stage is key to success in the entire process. Therefore, the transformation team helps the construction project teams use the platform since they are not familiar with using the online platform and

communicating directly with the suppliers. As for on-site events, competitions are integrated into the platform as they are analog versions of the platform. Although technology demonstration is still held in this period, the characteristics are a little different from the previous period. In this period, the successful solutions in the connecting platform are demonstrated and the project team shares the experience of the technology with the other project teams, which contributes to distributing the successful solution technologies widely to the other projects. In addition, field tour for the suppliers is held in this phase in order to keep providing the potential solvers with incentives to participate in the platform. Currently, MILT takes the initiative to hold infrastructure tourism where people visit construction sites of public infrastructure such as bridge and tunnel for sightseeing and feel attraction to the infrastructure and the construction sites [61]. In terms of change management, this phase is a change stage in that some construction project teams start using platform and collaborate with the cutting-edge technology suppliers to introduce new technologies into the sites. In addition, it is an unfreezing stage as well in that the technology demonstration events held by platform user teams allow the other project teams to recognize the value of the new technologies and give them incentives to participate in the connecting platform.

- Independent Operation (After 3 years)

In this phase, construction project teams take more actions and make more decisions by themselves compared with the previous period. They start to use the connecting platform independently without a lot of support from the transformation team due to the experience in previous period. As for technology demonstration event, the construction project teams start to hold the events by themselves. Also, the project teams may start to develop new technologies for near future operation as well as just introduce matured technologies because the project teams have learned new technologies and their future applications from the suppliers. In terms of change management, this period is a change stage in that many construction project teams start to use new ways to connect with the suppliers and acknowledge the value of new architecture. Also, this stage

is refreezing stage in that the new architecture is accepted by many project teams and becomes new norm.

In addition to the implementation for new architecture shown above, the implementation plan for introducing new technologies into sites is also important since the resisting forces against introducing technologies exists in the construction site even though the construction project team gets appropriate solutions from the suppliers successfully. Figure 32 shows the implementation plan for introducing new technologies into the site.

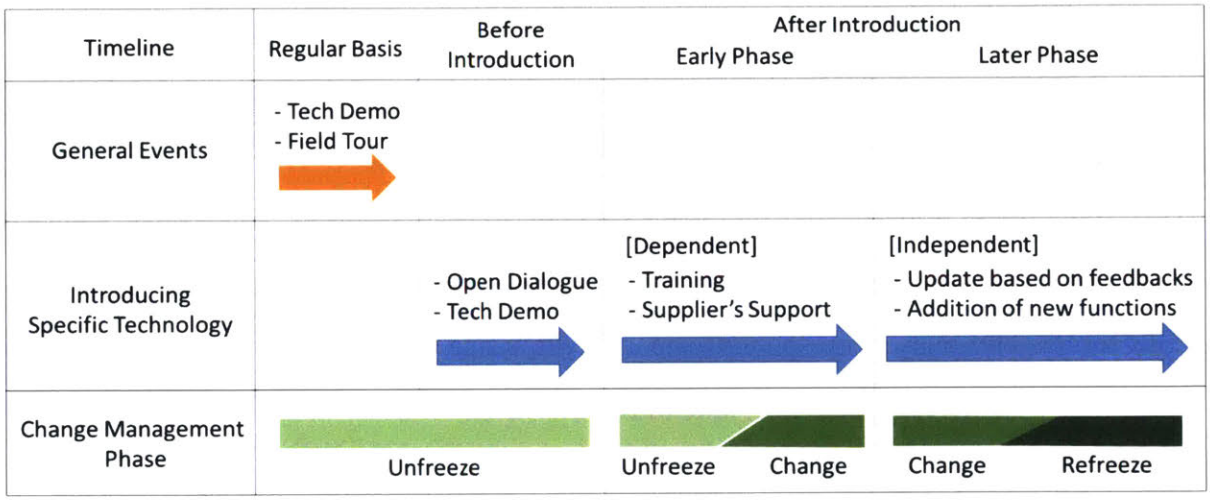


Figure 32: Implementation plan for introducing new technologies into the site

- Regular Basis

As Figure 31 shows, the construction project team members may have chances to join technology demonstration events where they acknowledge the potential values of new technologies. In addition, the construction project team holds field tours for the suppliers in their project sites where the workforce as well as the team members may have a feeling of closeness to the leading technology suppliers.

- Before Introduction

Before the construction project team actually introduces the selected solution technology into the site, performing the unfreezing activities such as open dialogue sessions and on-site technology demonstrations is crucial as the case study of Company B illustrates. Considering that some of the project team members and workforce may still have resisting forces against new technologies, seeing the technology by their own eyes and communicating with suppliers have important roles in mitigating the resisting forces.

- After Introduction (Early Phase)

In the early phase after introducing the new technology, the resisting forces may still exist and some problems with the technology may happen. As such, initial training should be performed carefully and contents of the training should be different depending on the needs as Company A in the case study does. Additionally, supplier's support is important in the early stage. Quick and correct responses to the requests from the project team and workforce contribute to mitigating the resisting forces. This phase corresponds to an unfreezing stage in that the construction project team and workforce start to recognize the value of the new technology by using it on site. Also, this is a change phase in that the project team and workforce start to change their method, from the conventional technology to the new one.

- After Introduction (Later Phase)

In the later phase after introduction, the attitude of the construction project team becomes independent rather than dependent on the suppliers. While the team tends to ask the suppliers questions or tell them to fix issues in the early phase, the team can propose updates of the new technology based on the feedbacks from the team members and workforce. Moreover, the team may generate new ideas about using the other new technologies to solve different issues in the site. The driving forces for introducing and developing new technologies will increase in this phase. In

terms of change management, this phase is refreezing stage as well as change stage in that new technologies are accepted by the construction project team and workforce, and become the new standard way.

5.4. Summary

This chapter consists of three steps of second half of ARIES framework. First, alternative architectures are generated based on the case studies in chapter 4. Second, the alternative architectures are evaluated based on the revised criteria and the combined architecture consisting of the connecting platform and on-site events is selected as the future architecture of the enterprise. Finally, the detailed architecture and the implementation plan are created based on the result of evaluation of the alternative architectures and risk assessment.

Chapter 6: Conclusion

6.1. Conclusion

The objective of this research is to investigate the application of a system architecting frame work to Japanese construction projects which are struggling to introduce and develop new technologies. The research questions are as follows,

- What are the root causes of the current situation of technology development in Japanese construction projects?
- What is the potential preferred architecture of construction projects to drive technology development?

ARIES framework is applied to this research in order to answer these questions. First, the current situation of the construction projects are analyzed from the perspectives of ten elements including enterprise landscape and stakeholder. While many factors in the ecosystem are driving technological development in the construction project sites, stakeholder analysis reveals that the relationships of the construction project team with the external stakeholder are weak. Especially, from the viewpoint of the other eight elements, it was made clear that the weak relationship with leading-edge technology suppliers led to the construction project team's lack of knowledge and information about new technologies, resulting in enhancing the resisting forces against introducing new technologies into the site. The mechanism described above is the answer to first research question.

In addition to the analysis of the current architecture of the enterprise, the future architecture is discussed through ARIES framework. The envisioned future is created based on the desired capabilities of the company and the enterprise to achieve the strategic goals. Subsequently,

case studies of different industries were performed in order to generate novel ideas about the future architecture. After the alternative architectures were generated, they were evaluated by an unweighted decision matrix. Consequently, a hybrid architecture consisting of the online connecting platform and the on-site events were selected as the future architecture. Finally, the strong interrelationships between the connecting platform and the on-site events were emphasized in the detailed architecture and the implementation plan, which led to increasing feasibility of the future architecture. This is the answer to the second research question.

Finally, in order to achieve success in transformation, it is important to take account of social aspects as well as technical aspects. It is not enough just to introduce new technology or to create the connecting platform from the technical perspective. New technologies produce beneficial effects only after the users acknowledge the values and take the initiative to use them, as well as the platform has positive impacts on technology development in the construction sites only when many users participate in the platform and keep high motivations to use it. In order to achieve it, it is important to take account of social aspects such as involving stakeholders and communicating with them, understanding their culture, developing an architecture to provide high incentives, and keep developing based on the feedbacks from the stakeholders.

6.2. Findings

ARIES framework enables the architecting team to analyze the targeted enterprise from a holistic point of view. Especially, ten elements enable one not only to view the enterprise from different perspectives but also to clarify the interrelationships among these perspectives, which help to identify the root causes of the complex problems. In this research, the weak relationship of the construction team with the leading-edge technology suppliers is the root cause for the other negative factors. Identifying the root cause results in clarifying the attention points for the future architecture as this research focuses on the relationships between the construction project team and

the suppliers in case studies. In addition to holistic view, ARIES framework encourages one to keep same viewpoints repeatedly through the entire process, which leads to validating the future architecture. For example, evaluation criteria are created based on the capabilities of the company and the enterprise discussed in the internal landscape analysis. Also, stakeholder and eight elements were taken into account in creating the envisioned future, evaluating the alternative architectures, and developing implementation plan as well as analyzing the current architecture. This process is similar to the Systems Engineering V Model which consists of a validation phase at the end [62]. Returning to the basic focus repeatedly is crucial in order to keep a consistency through the entire process.

Also, case studies have positive impacts on ARIES framework. The interview and field visit to the distribution center made the author re-realize that the field side's resisting forces against introducing new technologies exist in different industries and keeping communication through the entire process has an important role in the success of introducing new technologies into the sites. On the other hand, the interview with a technology supplier provided an important new insight that taking into account the supplier's needs is crucial when designing the future architecture of the user enterprise. Additionally, analyzing the case of InnoCentive helped to generating alternative architectures. Without this case study, the concept of the connecting platform would not have been generated.

From the perspective of systems thinking, the most valuable insight through this research is that interaction among multiple sub-systems is important for the entire system to work successfully. For example, the connecting platform works better by operating collaboratively with the on-site events. Also, the construction company can enhance technology development when the construction project teams and the headquarters work well with each other. Since each sub-system tends to have both strength and weakness, leveraging the strength and gaining support from the

other sub-systems to compensate for the weakness are crucial.

Finally, decentralization is an important key to achievement of robustness to the rapid change in the ecosystem, especially for the large corporations. In this research, the construction company will achieve robustness to change by introducing the connecting platform between the construction project teams and the suppliers which enables the teams to get more information and make more decisions independently. However, rapid change is not just limited to technology development but rather many aspects. The headquarters of the corporations need to keep in mind how the fields or branch offices can take the initiatives to make more decisions independently rather than assign jobs decided by the headquarters to them.

6.3. Limitation and Future Work

There are some limitations in this research. First of all, while it is better to involve the multiple members in the architecting team when designing the future architecture of the enterprise, this research is performed by a single person, the author. Although the author can gain a lot of findings through intensive literature review and case studies, some biases may exist in the entire process. One of the future areas would be discussing this research with the other employees in the construction company, which may provide new insights in the analysis of the current architecture, generate different ideas for the future architecture, create different evaluation criteria, and select the other architecture as the future one. Another limitation would be the number of case studies. In this research, the interviews and field visits were performed with one supplier and two user companies. Performing them with more suppliers and user companies would enable one to identify the commonalities and the differences among them, which is a powerful guide to generation of new architectures. Also, InnoCentive is the only company which is analyzed as an innovation platform. Analyzing the other innovation platforms with different architecture would provide some insights to improve the selected architecture in this research.

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