Innovation Management and Construction Phases in Infrastructure Projects

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Abstract: An innovation management approach for construction projects should take into account the opportunities that different phases of construction create for innovation. This research demonstrates how innovation behavior changes over a project life cycle using a mega-alliance as a case study. This paper shows what happens to innovation behavior when infrastructure projects are set up to generate innovations throughout a project life cycle using a key performance indicator system for measuring innovation. More than 500 innovations in an innovation database were categorized, analyzed, and classified according to their type, novelty, and benefit and then mapped against the project life cycle. Using a classification model developed for this research, a quantitative analysis of the innovations was performed to show the principal types of innovation and the changing trend of each type over construction project phases. The findings of this research verify variations in innovation creation throughout the project life cycle. The results show the importance of the initial stage of a project for novel technologies innovation and the different innovation types that are likely to be generated per phase. The findings will help project managers to design, develop, and apply the best innovation management policies considering both project phases and classified types of innovations. These findings strengthen the argument for developing an innovation management approach in the construction industry that is contingent on the phases of construction projects. **DOI: 10.1061/(ASCE)CO.1943-7862.0001608.** *© 2018 American Society of Civil Engineers.*

Author keywords: Innovation management; Project life cycle; Construction industry.

Introduction

The construction industry is traditionally seen as a low-technology sector with low levels of expenditure on activities associated with innovation. Loosemore and Richard (2015) stated, "The construction sector has come under particular scrutiny around the world as being a low-innovation sector," and referred to a survey in Australia ranking construction as the third lowest of seventeen sectors. A survey of UK construction firms conducted by Reichstein et al. (2005) showed that construction firms do not have the motivation to innovate; they claimed that construction firms are able to sustain themselves by meeting local needs of their undemanding customers but are not necessarily competitive or innovative. Holt (2015) believed that construction innovation tends to be ad hoc and project specific and also concluded that there was a lack of strategic plans for construction innovation. As the scale and complexity of construction projects increase, so do the consequences of failure. Being risk averse increases the tendency of both clients and companies involved in project delivery to continue with the previously tried and tested methods and designs, resulting in low levels of innovation (Tawiah and Russell 2008). However, Loosemore (2015) observed that, although many researchers show that the construction industry is not very innovative, companies involved throughout the life cycle of a construction project do in fact engage in day-to-day problem solving activities. He refers to these as hidden innovations (Loosemore 2015), which are often opportunistic and unplanned, coming in response to situations that arise in dealing with limitations of resources, changing working conditions, and unplanned challenges and events during the construction phase of projects.

The notion of innovation is often misunderstood among researchers and practitioners in the construction industry (Noktehdan et al. 2015). This is an ongoing challenge in the wider innovation research literature. Zairi (1994) made reference to this issue when he wrote, "What makes innovation challenging is the fact that it is very difficult to agree on a common definition." Over the years, researchers have proposed various definitions and classifications of innovation in order to overcome this challenge (Barrett and Sexton 2006; Fagerberg 2004; Linder et al. 2003; OECD 2005; Schumpeter 1961). In the construction innovation literature, a number of researchers have also offered various ways to classify construction innovation (Noktehdan et al. 2015; Slaughter 1998). Innovation research in the construction industry has mainly focused on systemic factors related to how various entities cooperate in construction projects (Blayse and Manley 2004; Dickinson et al. 2005; Sexton and Barrett 2003; Tatum 1987) or on organizational factors related to the individual entities involved in construction projects (Nam and Tatum 1997; Tatum 1989; Toole et al. 2013). However, construction is project based, and in order to better understand the dynamics of innovation in the construction industry, innovation needs to be studied throughout the life cycle of a project (Winch 1998).

The research in this paper answers the question, "How does the innovation behavior vary throughout the various phases of a construction project?" To date, life-cycle phase innovation has not been

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tested through empirical research. This is an important question, because if research findings verify variations in innovation behavior across the life cycle, that will strengthen the argument for developing an innovation management approach in the construction industry that is sophisticated and contingent on the phases of construction projects.

This research aims to empirically verify whether there are variations in innovation behavior throughout the construction project life cycle by analyzing over 500 innovations reported in a large infrastructure rebuild project in New Zealand. First, the innovations were classified into categories based on a literature review; next, the innovations were mapped against project phases. The findings of this review show the classification and analysis of the studied innovations and how these things changed through the project life cycle. The paper ends with a discussion of the results of the analysis of the changing nature of innovation activity throughout the project life cycle.

Innovation Classification

Innovation classification and measurement is a fairly well-established field in the mainstream innovation-management literature. However, as Garcia and Calantone (2002) note, there is little consistency in how innovations are classified. They state that "this abundance of typologies has resulted in the same name being used for different types of innovations and the same innovation being classified under different typologies."

OECD (2005) provides a classification system for types of innovation in their Oslo Manual with the following categories: product, process, marketing, and organizational. Other systems, including those from a review by Miller and Miller (2012), include:

- Garcia and Calantone (2002): radical, new, discontinuous, incremental, and imitative;
- Tidd et al. (2005): product, process, position, and paradigm; and
- Apax (2006): radical, architectural, modular, and incremental.

In comparing these definitions of innovation from the literature, three key, defining elements of innovation can be identified. First is the type of innovative idea or invention. Second is novelty; the minimum entry level for an innovation is that it must be novel or "new to the firm" (OECD 2005). The degree of novelty or newness can be defined as the extent of uncertainty associated with the implementation of the innovative idea within the context of its application (Shahbazpour 2010). Slaughter (1998) divided the novelty of construction innovations into five different levels: incremental, modular, architectural, system, and critical. The third element is benefits, or improvements in performance. In construction, performance has traditionally been measured in terms of costs, time, quality, and safety (Bassioni et al. 2004). Recently, environmental measures have also become an important performance indicator in construction projects (EPA 2007).

Each of these elements (type, novelty, and benefit) can alter the behavior of a given innovation through a project life cycle. In terms of type, whether an innovative idea is a product, a process, or an organizational method can result in different types of impact on productivity throughout a project's life cycle. In terms of novelty, the degree of novelty determines the significance of the impact a given innovation may have on productivity. For instance, an incremental change results in a much less significant impact on performance than a more radical and disruptive change. Finally, different innovations result in different sets of benefits and, therefore, have different impacts on productivity.

This review of innovation classifications has mainly been developed by analyzing innovations within the manufacturing and services context. While certain parallels can be drawn from the manufacturing literature, there are differences between manufacturing and construction. A review of the construction innovation literature shows only a small number of early studies that have approached aspects of innovation classification. Tatum (1988), for instance, developed a construction technology classification system based on the following categories: applied resources, materials and permanent equipment, construction processes, and construction product. Slaughter (1998) provided a classification system for construction innovation based on the degree of change resulting from the innovation and the expected linkages of the innovation to other parts of the system. Lim and Ofori (2007) argued that construction innovations should be classified according to their impact on competitive advantages for the stakeholders. They identified three categories: innovations that consumers are willing to pay for; innovations that reduce contractors' construction costs; and innovations that encompass intangible benefits, providing contractors with competitive advantages.

In order to better determine the impact and nature of the relationship between given innovations and overall project life cycle, type of innovation, novelty, and specific benefits, a detailed classification system was developed (Noktehdan et al. 2015). This classification system can be used to categorize the innovations implemented in a project. Noktehdan et al. (2015) identified three dimensions of the definition of innovation and used that as a basis for developing their classification system. The three dimensions are innovation type, novelty, and benefits (Fig. 1).

Project Life Cycle Phases and Innovation

Winch (1998) argued that "unlike other industries, innovations in construction are typically not implemented within the firm itself, but on the projects upon which the firms are engaged." This is supported by the assertion in Bygballe and Ingemansson (2014) that "projects are considered an invaluable arena for innovation." Construction projects move through distinctive life cycle phases, starting with their inception and ending with project termination and handover of the physical assets to the client (Lundin and Söderholm 1995).

Winch (2010) contended that construction projects are not only temporary but also dynamic in nature with respect to the project life cycle. He observed that the levels of uncertainty, the project organization's size, and the specialization of the people involved in a project vary significantly through the project life cycle. Ozorhon (2013) found that, despite emphasis on the firm level, much of construction innovation is codeveloped at the project level. She also believed that there are multiple stakeholders in construction projects and, therefore, innovation is best codeveloped at the project level (Ozorhon and Oral 2017).

Mapping innovations across the life cycle of projects is complicated by the number of project life cycle phases identified in the literature (Khang and Moe 2008; Liu et al. 2015; Pinto and Prescott 1988; PMBOK 2013; Slaughter 2000). The variety observed in project phase classifications confirms the fact that "there is no single best way to define an ideal project lifecycle" (PMBOK 2013). Typically, project life cycles are divided into phases based on the transfer of major deliverables (e.g., shifting from requirements to design, construction to operations, and so forth) and the specializations involved in the project (e.g., architects, designers, and subcontractors).

Typically, a project goes through four generic phases (PMBOK 2013): starting the project, organizing and preparing, carrying out the work, and closing the project. However, regardless of the

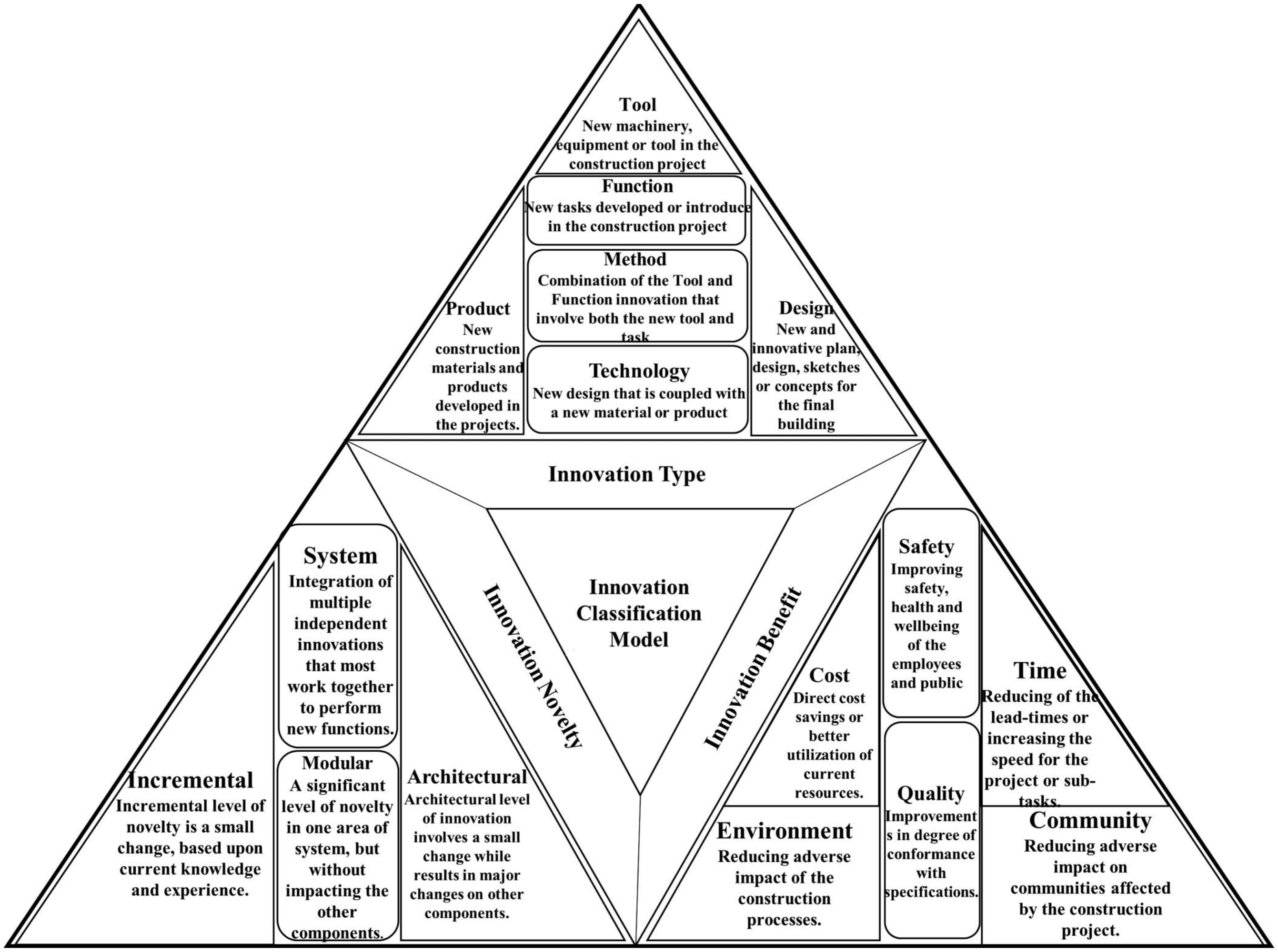

Fig. 1. Innovation classification model. (Data from Noktehdan et al. 2015.)

classification system used, a number of observations can be made about the changing characteristics of a project throughout its life cycle (Liu et al. 2015; PMBOK 2013);

The starting phase of a project is characterized by the smaller size of the project organization (in terms of costs and staffing levels), high levels of risk and uncertainty, and the greater influence of project stakeholders on the overall costs and outcomes of the project. Project aims assessment, feasibility study, and concept design have been identified as the critical activities in this phase (Liu et al. 2015; PMBOK 2013).

The next phase of a project is concerned with organizing and preparing details of the construction work. This involves detailed design, planning and tender process preparation, selection of contractors, and allocation of construction work.

The third phase of a project is generally characterized by a significant increase in the size of the project organization, increasing costs of change, and incremental reduction of risk and uncertainty. The bulk of work on a project is carried out in this phase. Management of time, costs, safety, staffing, conflicts, and communication are some of the most critical project success factors in this phase (Liu et al. 2015).

The final phase of a project is characterized by a rapid drop in the size of the project organization, significant reduction in risk and uncertainty, and project completion, as well as greater costs related to change and alterations.

Research Design

The research reported in this paper was conducted in three stages. The first stage consisted of a review of the literature in both construction management and innovation management, resulting in the selection of appropriate innovation classification systems and the project life cycle phase classification system. The second stage involved the application of the classification system to a database of over 500 reported innovations from a major infrastructure construction project in New Zealand referred to as Stronger Christchurch Infrastructure Rebuild Team (SCIRT). The final stage involved analysis of the results and reporting insights about the changing dynamics of innovation throughout the various phases of a construction project.

The SCIRT organization was established under an alliance agreement and was responsible for rebuilding horizontal infrastructure in Christchurch following the earthquakes of 2010 and 2011. The repair and reconstruction of infrastructure in the Canterbury region was one of the largest and most complex civil engineering projects in New Zealand's history (Christchurch City Council 2011). It was estimated that a large number of resources over a period of more than five years would be needed to cope with infrastructure repair and rebuild demands (CERA 2012). SCIRT adopted an alliance-like project management model to deliver the recovery of horizontal infrastructure projects. The SCIRT alliance was set up

Table 1. SCIRT innovation samples

Examples of SCIRT innovations	Novelty	Benefit	Types	Phase
Lightweight localized storm water pump station: lightweight localized pump stations utilize a new design philosophy that focuses on the use of horizontal axial flow pumps that enable shallow and lightweight structures to be used.	System	Quality/cost/time	Technology	Phase I
Bridge Street cathodic protection: while working on the repairs to the piers of the bridge street bridge, we installed cathode protection to the piers. The sacrificial anodes will prolong the period before corrosion of the reinforcement occurs, potentially increasing the lifespan of the piers by up to 25 years.	Architectural	Quality	Product	Phase III
Rationalization of wastewater pipe in Hawkesbury avenue: when the drawings for Hawkesbury avenue were reviewed by the delivery team, they indicated that a section of pipe could be removed if one additional manhole was installed at the position of the first lateral.	Architectural	Cost	Design	Phase III
Pipe bursting the water main in Buckingham: the Fulton Hogan team proceeded by pipe bursting the main rather than digging trenches as per the total ownership cost (TOC) for many community benefits.	Architectural	Quality/time	Method	Phase II
Confined space safety (CSS) workshop: these workshops were a great way to communicate updates to the team all at once; also discussed was the best way to communicate changes to our subcontractors.	Incremental	Cost/safety	Function	Phase III
Hydraulic aluminum shoring: aluminum hydraulic shores and shields are an excellent lightweight resource for working around existing utilities, supporting trench walls near structures, curbs, or sidewalks.	Modular	Quality/time	Tool	Phase III

in September 2011; it was made up of eight partner organizations, consisting of three owner participants and five nonowner participants. The three owner participants were the Christchurch City Council (CCC), Canterbury Earthquake Recovery Authority (CERA), and the New Zealand Transport Agency (NZTA), each of which played a different role. CCC and NZTA were the asset owners and funders; CERA was the Crown funder and was mandated to coordinate the overall rebuild activity on behalf of the central government. Five private construction companies were chosen as nonowner participants within the alliance. Together with their subcontractors and suppliers, the delivery teams were responsible for undertaking the repair and reconstruction works on the ground. The SCIRT learning legacy project shared knowledge and experiences gained from SCIRT projects. More than 148 projects developed diverse types of knowledge through the SCIRT project's life cycle. One statement regarding such valuable lessons and knowledge was that "the unique opportunity to explore and implement smarter and more effective ways of repairing and replacing Christchurch's horizontal infrastructure is too good an opportunity to miss" (SCIRT Learning Legacy 2016). Full access by the researchers to the SCIRT learning project was guaranteed through a contract between the University of Auckland and the SCIRT learning legacy project. Interviews, data, project monthly reports, and technical reports, with a database of more than 500 construction innovations were available for the researchers. Innovation was given special consideration when the SCIRT alliance was formed. Members of the alliance were encouraged to innovate and report on their innovations on a monthly basis as one of their key productivity indicators (KPIs), alongside traditional KPIs such as time, costs, and quality. These KPIs were linked directly to the pay/reward aspect of the contract. As a result, alliance members were motivated to report their innovations. Over 500 innovations had been reported by SCIRT at the time this research was conducted. The innovation database provided a unique opportunity to analyze and better understand the relationship between construction innovation and project phases.

For each reported innovation, the database contained a unique identification number, the project in which the innovation was implemented, a description of the innovative idea, its potential benefits, the date the innovation was introduced, and information regarding which organization member had initiated the innovation. Some of the reported innovations were also accompanied by pictures or sketches in order to better describe the innovation. Each of the reported innovations were analyzed and categorized based on the innovation classification system outlined in Fig. 1. To implement the classification model, the researchers first went through the database by carefully reading the explanation of each innovation. Furthermore, online reports and catalogs and personal observations were used in order to deepen the quality of judgments. The researchers judged each innovation's type, level of novelty, and benefits. For example, if an innovation was an upgraded material that was developed to address a site-related problem, then the innovation type was classified as product, with a modular level of novelty, and with either time, cost, or safety benefits. A second database was also provided to the researchers, containing information regarding the SCIRT projects, including the start and completion dates of various phases of each project. This information was used to determine which of the four generic project phases were associated with a given innovation. The following four phases were used:

- Phase 1—starting the project: including project definition, project allocation, and concept design;
- Phase 2—organizing and preparing: including detail design, total ownership cost (TOC), and construction allocation;
- Phase 3—carrying out the work: including construction and handover; and
- Phase 4—closing the project: that is, project completion.

Table 1 presents samples of SCIRT innovations that were classified based on type, benefits, novelty, and phase of project.

The categorization process was carried out by one researcher to ensure consistency of interpretation across the data set, with checking from another researcher for verification. Once completed, 20 innovations were selected randomly and categorized by three other researchers using the classification system. This was done to make sure the classification system was being applied appropriately. This protocol demonstrated that the classification process was well applied and the results were unbiased. Any uncertainty regarding the definitions were clarified through this process.

Research Results

The current research employed a quantitative method to find correlations between innovation behavior and project life-cycle phases. Chi-square tests were used on the research data. It was hypothesized

Table 2. Innovation types and SCIRT phases

	SCIRT project phases			
Innovation type	Phase 1	Phase 2	Phase 3	Row total
Design	6 11/76%	75 30/86%	8 3/10%	89 16/12%
Function	5 9/80%	7 2/88%	109 42/25%	121 21/92%
Method	9 17/65%	95 39/09%	10 3/88%	114 20/65%
Product	5 9/80%	41 16/87%	5 1/94%	51 9/24%
Technology	21 41/18%	7 2/88%	3 1/16%	31 5/62%
Tool	5 9/80%	18 7/41%	123 47/67%	146 26/45%

that the proportion of technology innovations undertaken by SCIRT would be largest in Phase 1 and would be lower in Phases 2 and 3. Phase 2 created the most method, product, and design types of innovations. The proportion of tool and function innovations were expected to be small in Phase 1, and process innovations were expected to be predominant in Phase 3. Because there were no innovations reported in the fourth and final phase of the projects, Phase 4 is not shown in the results.

A breakdown of the frequency of technology, method, product, design, tool, and function innovations in SCIRT with the database sorted into Phases 1–3 is shown in Table 2. The results support the hypothesis ($P = 0.0125 < 0.05$). Of the innovations in Phase 1, 41% fell under the technology type and only 9.8% fell under tool; this was followed by a complete reversal, with 39% of the innovations in Phase 2 being categorized as method and 42.5% categorized as function in Phase 3.

In order to gain more insight into the changing nature of innovation activity throughout the project life cycle, the data was analyzed from two perspectives. First, for each dimension of innovation (type, novelty, and benefit), the quantity of reported innovations in each project phase was examined. Second, for each project phase, the percentage composition of the various types of innovations was determined. Figs. 2–4 demonstrate the changing trends of innovation through the life cycle of the projects.

Trend-Based Approach

The data shows that the innovation types tools and functions had a similar trend, with significant increases during the construction phase of the projects (Phase 3). Product, design, and method innovations showed a marked increase from the start of projects to the organizing and planning phases of projects, with a decline during the construction phase of projects. The technology type of innovation showed a descending trend as projects moved to the planning and construction phases.

From a novelty perspective, the results show two trends. With the more novel types of innovation (system and architectural), the number of reported innovations increased significantly in the organizing and planning project phases and dropped off as projects moved into the construction phase. Modular and incremental innovations showed an increasing trend throughout the project life cycle, peaking during the construction phase.

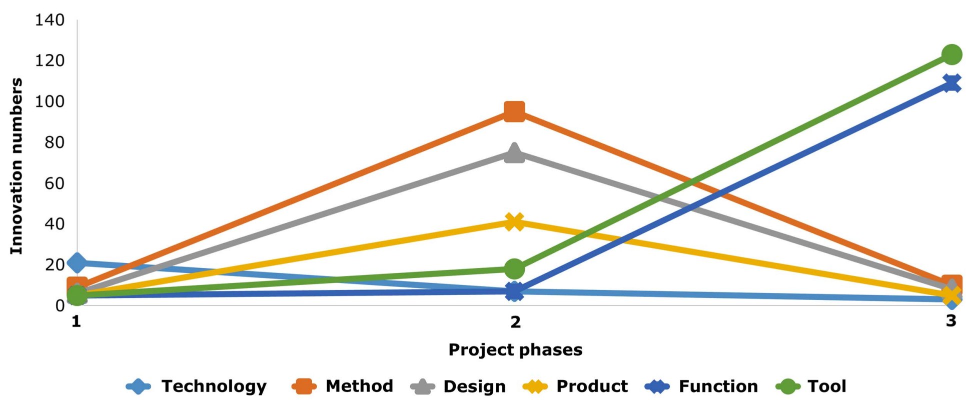

Fig. 2. Changing trend in number of reported innovations categorized by type in Phases 1–3.

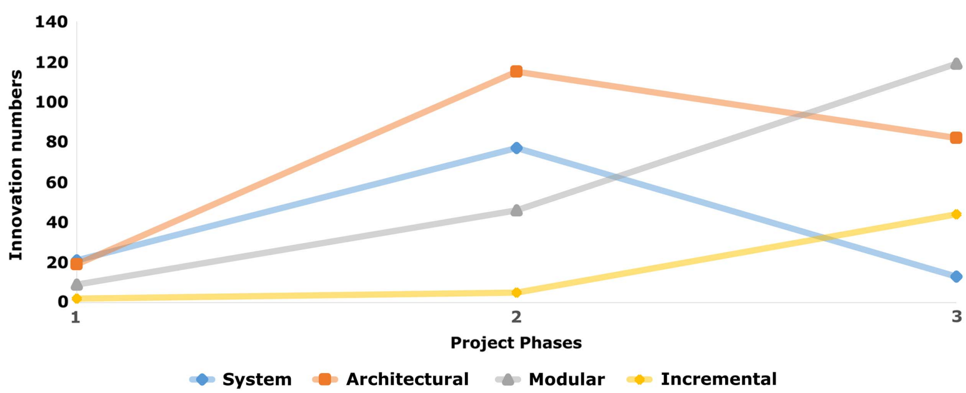

Fig. 3. Changing trend in number of reported innovations categorized by novelty in Phases 1–3.

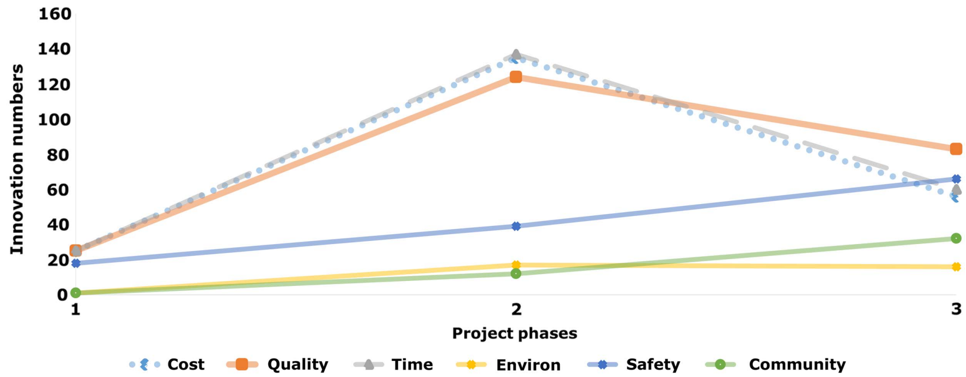

Fig. 4. Changing trend in number of reported innovations categorized by benefit in Phases 1–3.

In terms of benefits, innovations delivering benefits in the areas of time, cost, and quality showed very similar trends of significant increases during the organizing and planning project phases followed by decreases as projects moved to the construction phase. Safety and community-related innovations showed a steady increase as projects progressed through the life cycle. Environmental innovations showed a marked increase in the second project phase and stayed flat as projects moved on to the construction phase. There were numerous innovations with multiple benefits. For this analysis, if an innovation had benefits in multiple areas, it is shown in the sum for each benefit category.

Composition-Based Approach

A second perspective was employed by this research, to present the percentage combination of SCIRT innovations by different types, levels of novelty, and benefits in each of the three phases. Figs. 5–7 demonstrate the composition of innovation types, novelty, and benefits for each phase of the project. As illustrated, in the starting phase of projects, the technology and method innovations are the most prevalent in the type dimension, system and architectural innovations are the most common in the novelty category, and quality, time, and cost are the most common in the benefits category.

Fig. 5 illustrates the composition of reported innovations in Phase 1, in which technology is the predominant type, and system and architectural changes are seen in Fig. 5, with benefits mainly relating to time, costs, quality, and slightly behind, safety.

As shown in Fig. 6, the development of innovative designs and the introduction of novel construction products and methods were found to be the most prevalent types of innovation, focused on quality, time, and cost benefits. Furthermore, in Phase 2, the tendency is to focus on the system and architectural levels of novelty, because critical decisions are being made with regard to the details of the construction work.

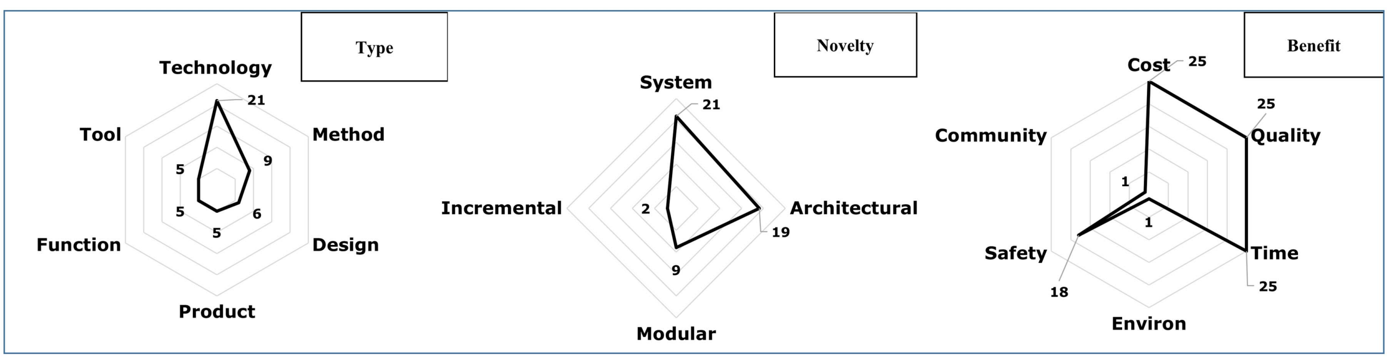

Fig. 5. Composition of reported innovations in Phase 1.

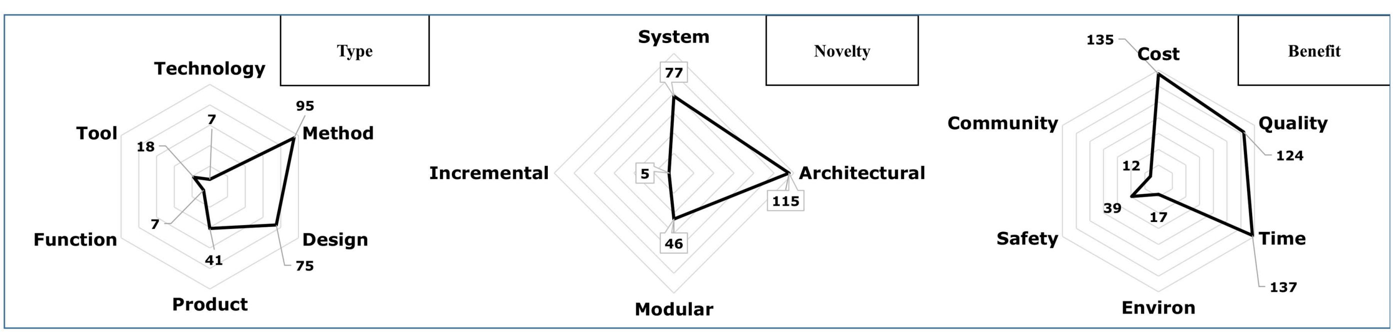

Fig. 6. Composition of reported innovations in Phase 2.

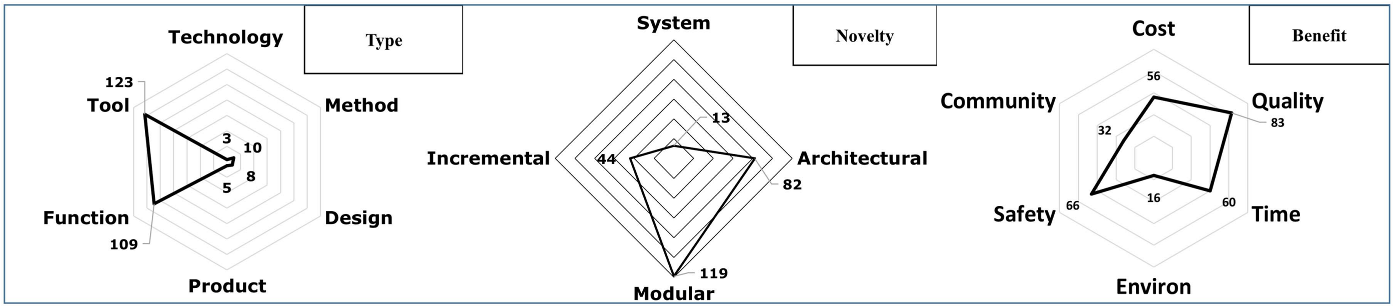

Fig. 7. Composition of reported innovations in Phase 3.

This is evident in the large shift toward the tool and function types of innovation, as shown in Fig. 7. Because the emphasis in Phase 3 is the on-time and on-budget delivery of the project, the reported innovations will have lower levels of novelty and have a larger variety of benefits in terms of quality, time, costs, safety, community, and the environment.

Discussion

The trend analysis of innovation behavior outlined in this paper represents several important and original contributions.

The results clearly demonstrate that innovation types differ across the project life cycle. The characteristics of the various phases of a project provide for situations and environments in which certain types of innovation become more prevalent. The changing dynamics of projects throughout the four phases allow for more consideration of a structured innovation management approach. Each of the four phases of projects could be organized to generate specific types of innovation.

- The starting phase of a project is characterized by the involvement of a smaller yet more influential team of stakeholders. If there is motivation to innovate (as was the case in the SCIRT project), this phase provides ample opportunity for the development and implementation of systemic technology and method innovations with potentially large impacts in the areas of costs, quality, time, and safety.
- Phase 2 of a project is concerned with organizing and preparing details of the construction work. This typically involves a substantial increase in collaborative design and planning activities among numerous entities, with expertise required for detailed design, planning and tender process preparation, selection of contractors, and allocation of construction work. If the climate encourages communication, collaboration, and innovation, this phase can lead to a large increase in innovation behavior and generate a substantial number of innovations.
- Phase 3 of a project is characterized by a significant increase in the size of the project. This creates an environment in which it becomes much more difficult to introduce systemic and large-impact changes; instead, the focus is shifted towards localized problem solving. This phase thus produces innovations of the tool type.
- The last phase of a project, closing, is an opportunity for documenting what happened during the project. Although there is less chance of innovation during this phase, documenting innovations created is important for future projects. A learning legacy for a project creates an opportunity to learn from innovations created and transfer them to future projects.

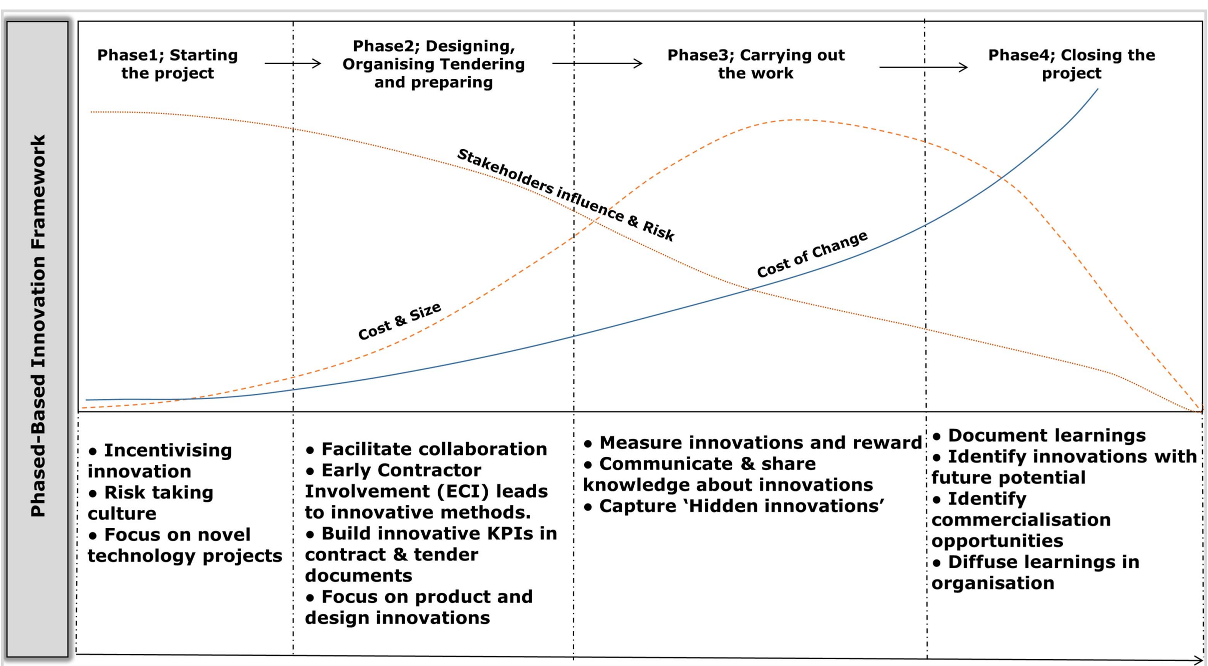

Fig. 8. Phase-based innovation framework.

Innovation Phase-Based Framework

Mapping innovations against a project life cycle has shown that there are many opportunities throughout a project to innovate and that these innovations have significant benefits for a project. Innovation generation is dynamic throughout the project life cycle. Changes in the characteristics and dynamics of innovation behavior throughout the project life cycle points to the need for a phase-based approach to the management of innovation in construction projects. Fig. 8 provides a suggested approach to innovation management throughout the construction life cycle. The dynamic environment in the different phases of the project life cycle create different conditions in each of the four phases for innovation management. Addressing this dynamic nature, the researchers developed best-practice advice for a phase-based approach to the management of innovation based on the results of this study.

The phase-based innovation framework facilitates predictive statements about differences between project phases in different project environments and with varying resources and constraints. The phase-based innovation framework provides ideas for innovating during the project.

Phase 1: In order to maximize innovation creation and development, the key innovation driver is to incorporate innovation as a KPI at the start of a project life cycle. Creating a need for innovation in first phase of the project by incentivizing innovation and creating a risk-taking culture with a focus on novel technology projects would maximize the likelihood of creating innovations in construction projects.

Phase 2: In the second phase of the project, various teams with different roles and responsibility should enhance innovation generation by creating a framework that facilitates collaboration, encourages early contractor involvement, and incorporates a pain/gain commercial model for innovation generation.

Phase 3: In Phase 3, innovations have a more minor influence on a project. Measuring and rewarding innovation generation and looking for hidden innovations is a major feature of this phase.

Phase 4: In order to enhance innovation generation and diffusion, the final phase of a project should be used to document learning, diffuse innovations more widely, and identify commercial opportunities from the innovations created.

Conclusion

This paper reported on a unique innovation generation program from a large alliance infrastructure organization. The results show that the potential to innovate changes depending on the project phase. The idea of looking at differences between project phases provides significant insights into innovation behavior on construction projects. The analysis presented in this paper provides empirical evidence and in-depth insights into the changing dynamics of innovation behavior throughout the project life cycle. The findings point to the need for the development of a phase-based approach to innovation management in construction projects. The model has operational relevance; that is, it suggests the sources and types of innovations a given project phase might expect to undertake successfully. The critical resources required and potential problems or constraints of each phase of an infrastructure project were identified. The potential for construction projects to generate innovations is great, especially when a process for innovation management and innovation incentivization is put in place. In the case of SCIRT, an overall strategy proved successful, generating over 500 innovations; the analysis of these innovations across the project life cycle showed considerable variations. Future construction projects and project managers can use this information to maximize innovation outcomes, with the result of improving innovation in the construction sector.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

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